Dissertation on

MORPHOLOGICAL ANALYSIS AND MORPHOMETRIC STUDY OF THE FORAMEN MAGNUM

Submitted in partial fulfillment for

M.D. DEGREE EXAMINATION

BRANCH- XXIII, ANATOMY

Upgraded Institute of Anatomy

Madras Medical College & Rajiv Gandhi Government General Hospital,

Chennai- 600 003

THE TAMILNADU Dr.M.G.R. MEDICAL UNIVERSITY

CHENNAI – 600 032

TAMILNADU

APRIL 2015

CERTIFICATE

This is to certify that this dissertation entitled

"MORPHOLOGICAL ANALYSIS AND MORPHOMETRIC STUDY OF THE FORAMEN MAGNUM"

is a bonafide record of the research work done by **Dr.M.ANURADHA**, Post graduate in the Institute of Anatomy, Madras Medical College and Research Institute, Rajiv Gandhi Government General Hospital, Chennai-03, in partial fulfillment of the regulations laid down by The Tamil Nadu Dr.M.G.R. Medical University for the award of M.D. Degree Branch XXIII-Anatomy, under my guidance and supervision during the academic year from 2012-2015.

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Rajiv Gandhi Government General Hospital
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INSTITUTIONAL ETHICS COMMITTEE
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CERTIFICATE OF APPROVAL

To
Dr.M.Anu Radha,
I year, M.D.Anatomy PG,
Madras Medical College, Chennai-3.

Dear M.Anu radha

The Institutional Ethics committee of Madras Medical College, reviewed and discussed your application for approval of the proposal entitled "Morphology and Morphometric study of the Foramen magnum in Human Adult Dry Skulls" No.08062013.

The following members of Ethics Committee were present in the meeting held on 11.06.2013 conducted at Madras Medical College, Chennai -3.

1. Dr.SivaKumar, MS FICS FAIS --- Chairperson
2. Prof. R. Nandhini MD -- Member Secretary
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3. Prof. Shyamraj MD -- Member
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   Prof of Surgery, MMC, Ch-3
7. Thiru. S. Govindsamy. BABL -- Lawyer
8. Tmt. Arnold Saulina MA MSW -- Social Scientist

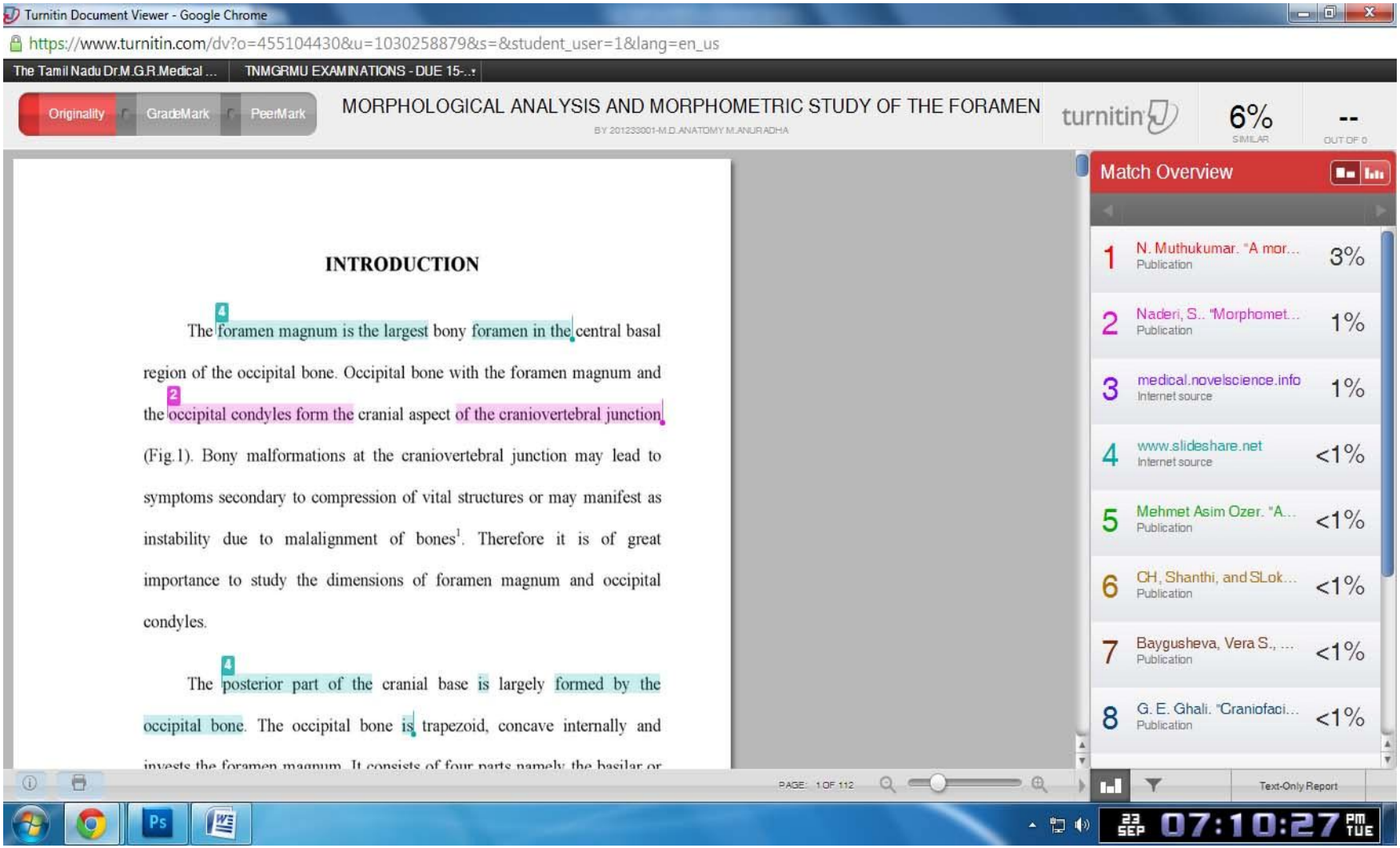
We approve the proposal to be conducted in its presented form.

Sd/ Chairman & Other Members

The Institutional Ethics Committee expects to be informed about the progress of the study, and SAE occurring in the course of the study, any changes in the protocol and patients information / informed consent and asks to be provided a copy of the final report.

R Nandini

Member Secretary, Ethics Committee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INTRODUCTION
The foramen magnum is the largest bony foramen in the central basal region of the occipital bone. Occipital bone with the foramen magnum and the occipital condyles form the cranial aspect of the craniovertebral junction (Fig.1). Bony malformations at the craniovertebral junction may lead to symptoms secondary to compression of vital structures or may manifest as instability due to malalignment of bones[1]. Therefore it is of great importance to study the dimensions of foramen magnum and occipital condyles.
The posterior part of the cranial base is largely formed by the occipital bone. The occipital bone is trapezoid, concave internally and
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I’m grateful to my **parents, my sister and my brother** who have helped making this study a reality.

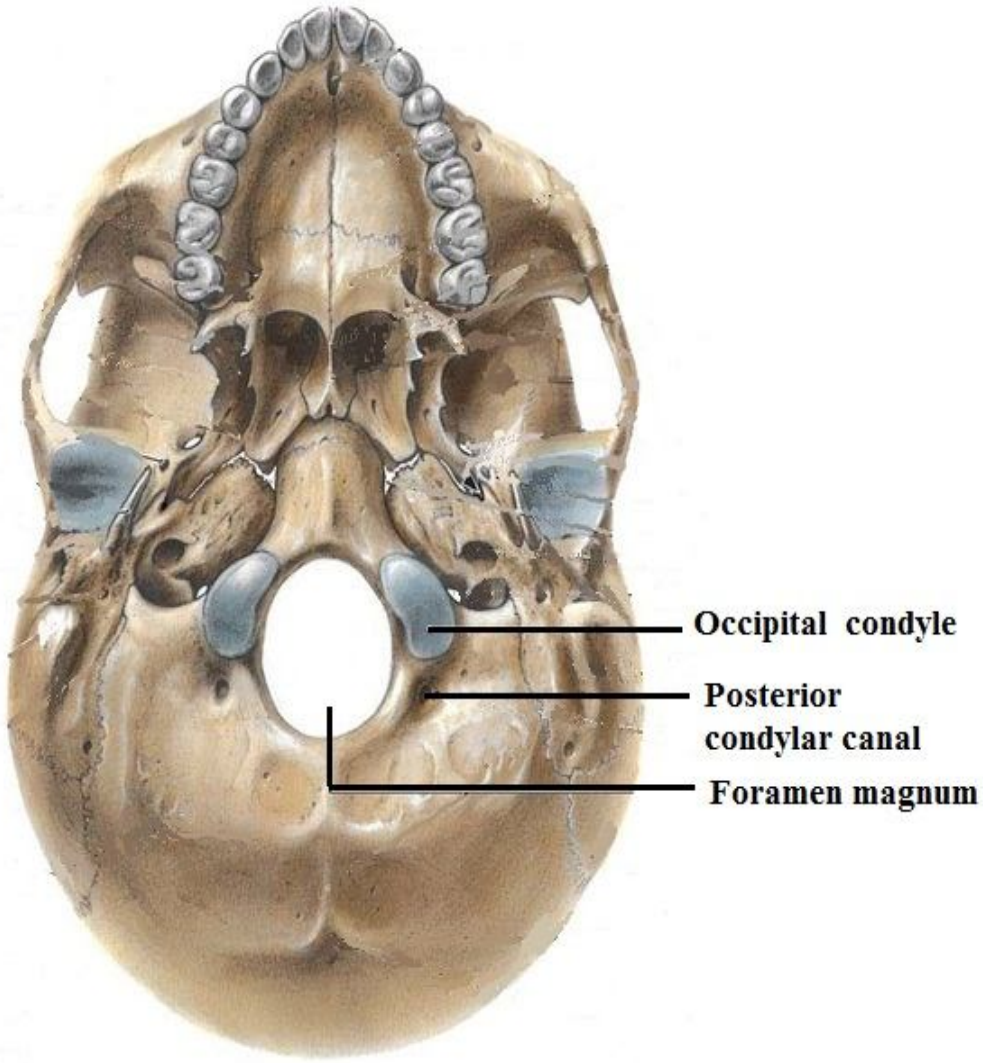
Above all, I thank the **ALMIGHTY GOD** who has showered His choicest blessings on me and guided me in every step of the dissertation.

CONTENTS

LEGEND

A ICD	-	Anterior inter condylar distance
AP	-	Antero Posterior
BCD	-	Bicondylar distance
CT	-	Computerised Tomography
FM	-	Foramen Magnum
HGC	-	Hypoglossal canal
LHGC	-	Left Hypoglossal Canal
LOC	-	Left Occipital Condyle
OC	-	Occipital Condyle
PCC	-	Posterior condylar canal
PICD	-	Posterior inter condylar distance
‘P’ value	-	Probability of observing the difference by chance
RHGC	-	Right Hypoglossal Canal
ROC	-	Right Occipital Condyle
SD	-	Standard deviation

Fig.1. External surface of Base of skull



MORPHOLOGICAL ANALYSIS AND MORPHOMETRIC STUDY OF THE FORAMEN MAGNUM

ABSTRACT

The foramen magnum is the oval shape opening situated at the base of the skull. The transcondylar approach is being increasingly used to access lesions of the Craniovertebral junction. Understanding the anatomy of the foramen magnum is important for skull base surgery.

The present study was aimed at analysing the foramen magnum morphologically and morphometrically.100 adult human dry skullsat the Institute of Anatomy, Madras Medical College and twenty cranial CT scans obtained from the archives of Barnard Institute of Radiology, Rajiv Gandhi Government General Hospital, Chennai were used for the study.

In the present study it was found that the foramen magnum was oval in 40% of the skulls studied. The mean AP diameter of the foramen magnum in dry skulls and cranial computerized tomographicscans were measured as 35.12±2.65mm and 35.03±0.95mm respectively. The mean transverse diameter of the foramen magnum in dry skulls and cranial CT were measured as 29.03±2.15mm and 28.79±1.17mm respectively. The mean maximum length of the right and left occipital condyle were measured as 23.85±2.12mm and 23.77±2.29mm respectively. The maximum and minimum width of the right occipital condyle were measured as 13.2 ±1.36mm and 6.86±1.34mm respectively. The maximum and minimum width of the left occipital condyle

were measured as 13.44±1.41mm and 7.04±1.26mm respectively. The mean length of right and left occipital condyle were measured as 23.11±0.73mm and 23.20±0.74mm respectively in cranial CT.The mean width of right and left occipital condyle were measured as 12.92±0.65mm to 12.88±0.69mm respectively in cranial CT. The bicondylar distance, anterior intercondylar distance and the posterior intercondylar distance were measured as 47.23±3.10mm, 20.81±2.40mm and 41.97±1.67mm respectively. The posterior condylar canal was present in 40 skulls on right side and 49 skulls on left side. The Hypoglossal canal septum was present in 24%. The mean distance between intracranial edge of right hypoglossal canal and anterior margin of right occipital condyle was measured as 11.02±1.29mm and from left hypoglossal canal and anterior margin of left occipital condyle was measured as10.93±1.3mm.The mean distance between intracranial edge of right hypoglossal canal and posterior margin of right occipital condyle was measured as 12.26±0.59mm and from left hypoglossal canal and posterior margin of left occipital condyle was measured as12.25±0.59mm.

The data obtained will be useful for neurosurgeons in analyzing the anatomy of Craniovertebral junction for preoperative planning and management of skull base surgery. The findings will also be enlightening for Radiologists, Orthopedicians, Anthropologists, Morphologists and Clinical Anatomists.

KEY WORDS: Foramen magnum, Occipital condyle, Hypoglossal canal, Transcondylar approach.

INTRODUCTION

The foramen magnum is the largest bony foramen in the central basal region of the occipital bone. Occipital bone with the foramen magnum and the occipital condyles form the cranial aspect of the craniovertebral junction (Fig.1). Bony malformations at the craniovertebral junction may lead to symptoms secondary to compression of vital structures or may manifest as instability due to malalignment of bones[1]. Therefore it is of great importance to study the dimensions of foramen magnum and occipital condyles.

The posterior part of the cranial base is largely formed by the occipital bone. The occipital bone is trapezoid, concave internally and invests the foramen magnum. It consists of four parts namely the basilar or basioccipital part, squamous part and two lateral or condylar parts. The basilar part is quadrilateral in shape and lies in front of foramen magnum. The squamous part is an expanded plate and lies posterosuperior to the foramen magnum and the two lateral or condylar or exoccipital parts lie on each side of the foramen magnum.[55,14]

The occipital bone provides attachment to the muscles of neck and back. It articulates with the first cervical vertebra at atlanto-occipital joints.

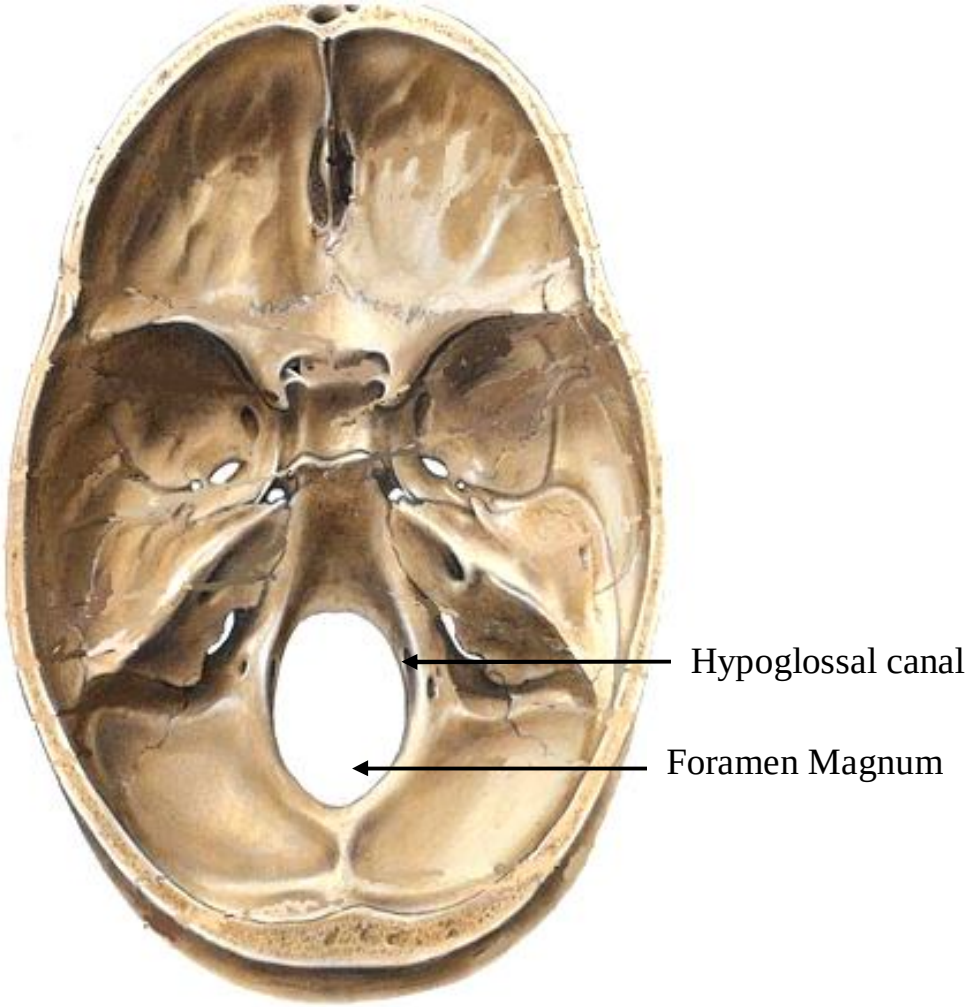
Foramen magnum is unpaired, oval and oriented obliquely. The anteroposterior diameter of the foramen magnum is more than the transverse diameter. The anterior margin of the foramen magnum is encroached on each side by the occipital condyles which project down to articulate with the superior articular facets of the atlas. Anterior and posterior atlanto occipital membranes are attached to the corresponding margins of the foramen magnum.

The structures adjacent to the foramen magnum are the bilateral occipital condyles, jugular foramina, mastoid notches, squamous parts of the occipital bone, hypoglossal canals (anterior condylar canal) and posterior condylar canals. The posterior cranial fossa communicates with the vertebral canal through the foramen magnum.

The following structures traverse through the foramen magnum:

- Anteriorly, the upper surface of the basilar part of the foramen magnum gives attachment to apical ligament of dens and membrana tectoria which is the upward prolongation of the posterior longitudinal ligament.
- Its wider posterior part transmits the lower end of medulla oblongata which continues down as the spinal cord.
- Cranial meninges
- Vertebral arteries

Fig.2. Internal surface of Base of skull



- Anterior and posterior spinal arteries
- Spinal accessory nerve
- Upper three cervical meningeal nerves

OCCIPITAL CONDYLE

The occipital condyles are oval or reniform in shape, with their long axes converging anteromedially. On the medial aspect of each condyle, a tubercle for the alar or check ligament is present.[25]

The anterior one third of each condyle extends forwards on to the basilar part of the bone. The site of union between the basilar and condylar parts is marked by the anterior condylar or hypoglossal canal (Fig.2). The hypoglossal canal is directed laterally and slightly forwards, and transmits the hypoglossal nerve, a meningeal branch of the ascending pharyngeal artery and an emissary vein. Behind each condyle there is a condylar fossa. In some cases there is a posterior condylar canal which transmits the emissary vein.

The third occipital condyle is an occasional tubercle which projects from the anterior border of the foramen magnum to articulate with the dens of the axis.[25]

BASILAR PART

The basilar or basioccipital part is a bar of bone that extends upwards and forwards from the foramen magnum and fuses with the basisphenoid. Its internal or cerebral surface is concave from side to side. It supports pons and medulla.

In the external surface, pharyngeal tubercle is present which gives attachment to the fibrous pharyngeal raphe.

BLOOD SUPPLY OF FORAMEN MAGNUM

The duramater in the anterior and posterior part of the foramen magnum is supplied by the anterior and posterior meningeal artery, which are branches of vertebral artery.[6] Posterolateral part of foramen magnum is supplied by the mastoid branch of the occipital artery.[20]

Aim of the study

AIM OF THE STUDY

The Foramen Magnum (FM) is an oval shaped opening situated at the base of the skull. The surgery for craniovertebral junction anomalies and skull base tumors at FM, poses a challenge for neurosurgeons. Understanding the bony anatomy of FM is essential for any surgery at the craniovertebral junction for safeguarding the vital structures. The primary goal of FM surgery is to decompress the vital neural structures without compromising their function and craniovertebral stability.[21]

Craniovertebral junction abnormalities can be broadly classified as congenital, developmental, acquired, tumors, infective, inflammatory or traumatic. Meningiomas are the most common primary skull base tumour. About 40% to 50% of meningiomas involves skull base. The incidence of skull base meningioma is 2 per 100,000 per year. The male to female ratio is 1:2.2 in patients aged from 12 to 81 years.[60] FM meningioma mostly presents on the anterior margin of FM. It can be diagnosed by CT scan and confirmed by MRI scan. Innovative skull base approaches are now practised to achieve total surgical removal of basal meningiomas.

Posterior or lateral FM meningiomas are resected by using inferior suboccipital approach. Anterior or ventral FM meningiomas can be resected by the transcondylar approach. It is also called by different names as

far-lateral, posterolateral or extreme lateral approach.[60] In the far-lateral approach craniovertebral stability is not affected due to minimal removal of occipital condyles. It also provides an adequate exposure to ventral brainstem. Many varieties of lateral approaches have been reported including transfacetal approach, partial or complete transcondylar approach, extreme lateral transjugular approach and transtubercular approach.[60,28]

Hence, neurosurgeons performing posterior or lateral approaches to Craniovertebral junction surgery should be familiar with the normal anatomy and possible variations of the foramen magnum, occipital condyle and hypoglossal canal to reduce the surgical morbidity.

The aim of the present study is to analyse the FM and occipital condyles morphologically and morphometrically. Hopefully the data will be beneficial to neurosurgeons, radiologists and orthopaedicians for preoperative planning and management of Craniovertebral junction surgeries.

The parameters studied are :

1. Shape of the foramen magnum
2. Maximum anteroposterior diameter of the foramen magnum
3. Maximum transverse diameter of the foramen magnum
4. Presence of protrusion of occipital condyle into the foramen magnum

5. Length of the right occipital condyle
6. Maximum width of the right occipital condyle
7. Minimum width of the right occipital condyle
8. Length of the left occipital condyle
9. Maximum width of the left occipital condyle
10. Minimum width of the left occipital condyle
11. Bicondylar distance
12. Anterior intercondylar distance
13. Posterior intercondylar distance
14. Presence of Posterior condylar canal
15. Presence of Septum of the hypoglossal canal
16. Distance between intracranial edge of right hypoglossal canal and anterior margin of right occipital condyle
17. Distance between intracranial edge of right hypoglossal canal and posterior margin of right occipital condyle
18. Distance between intracranial edge of left hypoglossal canal and anterior margin of left occipital condyle
19. Distance between intracranial edge of left hypoglossal canal and posterior margin of left occipital condyle

Review of literature

REVIEW OF LITERATURE

1) SHAPE OF THE FORAMEN MAGNUM

Khalil Awadh Murshed et al [30](2003) in their study of spiral CT scan of the FM of 110 normal subjects reported that the FM shape was oval in 8.1%, egg shaped in 6.3%, round 21.8%, pentagonal in 13.6%, tetragonal in 12.7%, irregular type(B) in 9.09%.hexagonal in 17.2%, and irregular type(A) in10.9%.

Muthukumar N et al [35](2005) in their study of 50 dry skulls, stated that the FM was found to have round shape in 46%.

P. Chethan et al [41](2011) in their study of 53 skulls, observed that the FM was round shaped in 22.6%, egg shaped in 18.9%, oval in 15.1%, irregular in 15.1%, tetragonal in 18.9%, hexagonal in 5.6% and pentagonal in 3.8% of the cases.

Emel AVCL et al [9](2011) in their study of 30 skulls, found that the FM was oval in 58%.

Radhakrishnan S.K et al [46](2012) studied 100 adult dry skulls, and observed that the FM was oval in 39%, round in 28%, tetragonal in 19% and pentagonal in 14% of the cases.

Radhakrishnan P et al [45](2012) in their study of 250 Cranial CT of normal subjects between the ages of 18 and 80 years, stated that the shape of the FM was oval in 35.2%, hexagonal in 24.8%, round in 7.6%, trigonal in 1.6%, pentagonal in 12.4%, tetragonal in 6.8% and irregular in 11.6%.

Gobbur et al [19](2013) in their study of cranial CT of 150 subjects, stated that the FM was found to be round in 40% and oval in 30%.

K. Natsis et al [31](2013) in their study of 143 skulls, reported that the shape of the FM was two semicircles in 25.9%.It was pear shaped in 22.4%, egg shaped in 21%, oval in14.7%, rhomboid in14%, round in 1.4% and irregular in 0.7%.

Jose Aderval Aragao et al [26] (2014) studied about 110 adult dry skulls and observed that the shape of FM was pear in 37%, oval in 5.45%, tetragonal in 10.91%, pentagonal in 2.73%, round in 15.45%, hexagonal in 9.09%, heptagonal in 1.82% , biconvex in 10.91% and irregular in 6.36% of subjects.

2) MAXIMUM ANTEROPOSTERIOR DIAMETER OF THE FORAMEN MAGNUM (FM)

Georges Olivier et al [18] 1975) studied 125 human dry skulls and reported that the mean AP diameter of the FM was 35.7mm.

Wanebo et al [58](2001) studied about 32 dry skulls and reported that the mean AP diameter of the FM was 36mm.

Khalil Awadh Murshed et al [30](2003) in their study of about 110 cranial CT scans, found that the mean AP diameter of the FM in male and female was 37.2±3.4 and 34.6±3.16 respectively.

Muthukumar. N et al [35](2005) studied about 50 adult dry skulls. They found that the maximum AP diameter of FM was 33.3 mm.

Emine et al [10](2006) studied 59 adult dry skulls and reported that the AP diameter of the FM was in between 29.7mm and 39.7mm with an average of 34.8±2.2mm.

Manoel. C et al [33](2009) in their study of 215 (139 males and 76 females) adult human dry skulls reported that the mean AP diameter of the FM of male and female were 35.7±0.29 mm and 35.1± 0.33 mm respectively.

Ivan Claudio Suazo Galdames et al [22](2009) studied 211 skulls and concluded that the mean AP diameter of the FM of male and female were 36.5 mm and 35.6 mm respectively.

Philipp Gruber et al [43](2009) studied about 111 adult dry skulls and they reported that the mean AP diameter was in the range of 30.1mm to 42.6mm with an average of 36.6mm.

Fatma Hayat Eridil et al [13](2010) studied 54 cranial CT scans and the mean AP diameter of the FM was reported as 35.58±4mm.

P. Chethan et al [41] 2011) studied about 53 dry skulls and reported that the mean AP was 31±2.4mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, recorded the mean AP diameter of the FM as 34.5mm.

Ukoha U et al [57](2011) reported the mean AP diameter of the FM of male and female as 36.26mm and 34.39 mm respectively.

F.Burdan et al [11](2012) observed the mean AP diameter of the FM of male and female as 37.06mm and 35.57 mm respectively in 313 CT scans.

Gagandeep Singh et al [15](2012) studied about 50 skulls. They reported that the mean AP diameter of the FM of male and female were 33.54mm and 32.31mm respectively.

Gautam Kanodia et al [17](2012) studied about 100 adult dry skulls and 100 CT scans of posterior fossa. They reported that the mean AP diameter of the FM was 34.1±0.29mm in dry skull group and 33.1±0.35 in CT scan.

Osunwoke E.A et al [38](2012) studied 120 adult human dry skulls and the mean AP diameter of the FM was reported as 36.11±0.24mm.

Radhakrishnan S.K et al [46](2012) studied 100 adult human dry skulls, and reported that the mean AP diameter of the FM of male and female were 34.04±2.36mm and 31.72±2.14mm respectively with an average of 32.88mm.

Radhakrishnan P et al [35](2012) in their study of 250 Cranial CT of normal subjects between the ages of 18 and 80years observed that the AP diameter of FM was in the range of 25.8mm to 45.9mm with the average of 35.76±3.4mm.

A.T.Uthman et al [3](2012) in their study of 88 cranial CT scans reported that the AP diameter of the FM of male was in between 29.3mm and 40.8mm with an average of 34.9mm and that of female was in between 26.9mm and 38mm with an average of 32.9mm.

Fathy Ahmed Fetouh et al [12](2013) studied about 100 adult dry human skulls and recorded that the AP diameter of FM was in the range of 31mm to 40.2mm with the average of 34.94mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, reported that the mean AP diameter of the FM was 35.53±3.06mm.

Shanthi CH et al [52](2013) studied about 100 adult human dry skulls and reported that the mean AP diameter of the FM of male and female were 37.1mm and 33.8mm respectively.

S.K.Jain et al [53](2013) in their study of 68 skulls, reported that the mean AP diameter of the FM of male and female were 36.9±0.2mm and 32.9±0.3mm respectively.

Surwase Ramdas Gopal rao et al [54](2013) in their study of 100 cranial C.T. scans reported that the mean AP diameter of the FM of male and female were 33.9±2.61mm and 32.35±3.16mm respectively.

Roma Patel et al [47](2014) studied about 100 adult dry human skulls and recorded that the AP diameter of the FM was in the range of 26mm to 40.2mm with the average of 33.7mm.

Yogesh Yadav et al [59](2014) in their study of 96 skulls, reported that the mean AP diameter of the FM of male and female were 35.22± 2.17mm and 33.1±2.04mm respectively.

3) MAXIMUM TRANSVERSE DIAMETER OF THE FORAMEN MAGNUM (FM)

Georges Olivier [18](1975) studied about 125 adult human dry skulls and reported that the mean transverse diameter of the FM was 30.34mm.

Wanebo et al [58](2001) studied about 32 dry skulls and reported that the mean transverse diameter of the FM was 31mm.

Khalil Awadh Murshed et al [30](2003) in their study of cranial CT of 110 normal subjects between the age of 18 and 80 years, observed that the mean transverse diameter FM in male and female were 31.6±2.99mm and 29.3.±2.19mm respectively.

Muthukumar N et al [35](2005) studied about 50 adult human dry skulls. They found that the maximum transverse diameter of FM was 27.9 mm.

Emine et al [10](2006) studied about 59 human adult dry skulls and reported that the transverse diameter of the FM was in between 24.4mm and 38.6mm with an average of 29.6±2.4mm.

Manoel. C et al [33] (2009) in their study of 215 (139 males and 76 females) adult dry skulls reported that the mean transverse diameter of the FM of male and female were 30.3±0.2 mm and 29.4± 0.23 mm respectively.

Ivan Claudio Suazo Galdames et al [22](2009) studied 211 skulls and concluded that the mean transverse diameter of the FM of male and female were 30.6 mm and 29.5 mm respectively.

Philip Gruber et al [43](2009) studied about 111 adult human dry skulls and reported that the mean transverse diameter of the FM was in the range of 25.0mm.to 38.9mm with an average of 31.1mm.

Fatma Hayat Eridil et al [13](2010) in their study of 54 cranial CT scans stated that the mean transverse diameter of the FM was 29.84mm.

P. Chethan1 et al [41](2011) studied about 53 dry skulls and reported that the mean transverse diameter was 25.2±2.4mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, reported that the mean transverse diameter of FM was 29mm.

Ukoha U et al [57](2011) in their study, the mean transverse diameter of the FM of male and female were 30.09mm and 28.16mm respectively.

Gagandeep Singh et al [15](2012) studied about 50 skulls (26 males and 24 females). They reported that the mean transverse diameter of the FM of male and female were 27.77mm and 27.21mm respectively.

Gautam Kanodia et al [17](2012) studied about 100 adult dry human skulls and 100 CT scans of posterior fossa. They reported that the mean transverse diameter of the FM was 27.5±o.25mm in dry skull group and 27.6±0.31 in CT scan.

Osunwoke E.A et al [38](2012) in their study of 120 human dry skulls, reported that the mean transverse diameter of the FM was 29.65±0.24mm.

F.Burdan et al [11](2012) in their study of the mean transverse diameter of the FM, reported that the values for male and female were 30.95mm and 32.98 mm respectively in 313 CT scans.

Radhakrishnan S.K et al [46](2012) studied 100 adult human dry skulls. They reported that the mean transverse diameter of the FM of male and female were 28.63±1.89mm and 25.59±1.64mm respectively.

Radhakrishnan P et al [45](2012) in their study of 250 Cranial CT of normal subjects between the age of 18 and 80years stated that the mean transverse diameter of FM was in between 39.1mm and 22mm with the average of 29.79±2.85mm.

A.T.Uthman et al [3](2012)) in their study of 88 cranial CT scans reported that the mean transverse diameter of the FM of male 24mm.to 34.8mm with an average of 29.5mm and that of female was in between 22.3mm and 31.8mm with an average of 27.3mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, observed that the mean transverse diameter of the FM was 30.31±2.79mm.

Shanthi CH et al [52](2013) studied about 100 adult human dry skulls and reported that the mean transverse diameter of the FM of male and female were 32.0mm and 30.4mm respectively.

S.K.Jain et al [5] (2013) in their study of 68 skulls, reported that the mean transverse diameter of the FM of male and female were 31.5±0.27mm and 29.5±0.28mm respectively.

Surwase Ramdas Gopalrao et al [54](2013) in their study of 100 cranial CT scans reported that the mean transverse diameter of the FM of male was 28.05±2.22mm and that of female was 26.88±2.96mm.

Roma Patel et al [47](2014) studied about 100 adult dry human skulls and recorded that the transverse diameter of FM was in the range of 33.5mm to 21.5mm with the average of 28.29mm.

Yogesh Yadav et al [59](2014) in their study of 96 skulls, reported that the mean transverse diameter of the FM of male and female were 27.6±2.26mm and 26.71±1.76mm respectively.

4) PROTRUSION OF OCCIPITAL CONDYLE (OC) INTO THE FORAMEN MAGNUM.

Muthukumar N et al [35](2005) in their study of 50 dry skulls, observed that the OC protrude into the FM in 20% of adult dry skulls.

P. Chethan1 et al [41](2011) studied about 53 skulls and found that the OC protruded into the FM in 20.7% of skulls.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, observed that the OC protruded into the FM in 57% of skulls.

5) LENGTH OF THE RIGHT OCCIPITAL CONDYLE (ROC)

Georges Olivier [18](1975) studied about 125 adult human dry skulls and stated that the mean length of the ROC was 23.75mm.

Daniel J et al [7](2001) in their study of 522 adult dry skulls, recorded that the mean maximum length of ROC of black male and female were 23.2mm and 22.0mm respectively and white male and female were 24.7mm and 22.8mm respectively.

Muthukumar N et al [35](2005) studied about 50 adult human dry skulls. They found that the mean length of the ROC was 23.6mm.

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls, found that the length of the ROC was 23.6mm.

Emine et al [10](2006) studied about 59 human adult dry skulls and reported that the length of the ROC was in the range of 19.7mm to 30.7mm with an average of 24.4±2.2mm.

Nehi'r Barut et al [36](2009) studied about 56 dry human skulls. They found that the mean length of the OC was 23.1mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, reported that the mean maximum length of ROC was in the range of 18.2mm to 28.7mm with an average of 23.7±2.6mm.

J.T.Hong et al [27](2011) studied 13 frozen cadaveric specimens and reported that the mean length of OC was 22.9±2.5mm.

Mehmet Asim Ozer et al [34](2011) studied 144 adult dry skulls and recorded that the length of ROC was 23.9±3.4mm.

di Vasudha V. Saralayaet al [8](2012) studied about70 adult human dry skulls. They reported that the mean length of the ROC was 21.9mm.

Tien V et al [56](2011) in their study of 170 cranial CT scans reported that the mean length of ROC was 22.2±2.1mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls found that the mean length of the ROC was 24±3.6mm.

Fathy Ahmed Fetouh et al [12](2013)studied about 100 adult dry human skulls and recorded that the mean maximum length of ROC varied from 18mm to 31mm with an average of 23.5mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls found that the length of ROC was 25.60±2.91mm.

Pooja Gangrade et al [44](2013))studied 100 adult dry skulls and recorded that the mean length of ROC of male and female was 25.55mm and 23.1mm respectively.

Bello S.S et al [4](2013) studied about 240 cranial CT scans and reported that the mean length of ROC was 23.5±2.7mm.

Parvindokht Bayat et al [39](2014) in their study of 50 adult dry skulls, reported that the mean maximum length of ROC was in the range of 4mm to 27mm with an average of 19.43±3.27mm.

6) MAXIMUM WIDTH OF THE RIGHT OCCIPITAL CONDYLE

Georges Olivier [18](1975) studied about 125 adult human dry skulls and reported that mean width of the ROC was 11.5mm.

Daniel J et al [7](2001) in their study of 522 adult dry skulls, reported that the mean maximum width of ROC of black male and female were 12.8mm and 12mm respectively and white male and female were 12.3mm and 11.7mm respectively.

Muthukumar N et al [35](2005) studied about 50 adult human dry skulls. They found that the mean width of the ROC was 14.72mm.

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls, reported that the width of the ROC was 10.6mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the width of the ROC varied from 10.3mm to 16.9mm with an average of 13±1.5mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, reported that the maximum width of ROC was in the range of 9 mm to 14.5 mm with an average of 12.2±1.2mm.

J.T.Hong et al [27](2011) studied 13 frozen cadaveric specimens and reported that the mean width of OC was 14.1±1.8mm.

Mehmet Asim Ozer et al [34](2011) studied 144 adult dry skulls and recorded that the width of ROC was 11.9±2.3mm.

Tien V et al [56](2011) in their study of 170 cranial CTscans reported that the mean width of ROC was 11.2±1.4mm.

di Vasudha V. Saralaya et al [8](2012)studied about 70 adult human dry skulls and reported that the mean width of the ROC was 11.26mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls, reported that the mean width of the ROC was 13.4±1.4mm.

Fathy Ahmed Fetouh et al [12](2013) studied about 100 adult dry human skulls and recorded that the mean maximum width of ROC varies from 9.5mm to 18mm with an average of 13.58mm.

Bello S.S et al [44](2013) studied about 240 cranial CT scans and reported that the mean width of ROC was 12.8±1.7mm.

Parvindokht Bayat et al [39](2014) in their study of 50 adult dry skulls, reported that the mean maximum width of ROC ranged from 6mm to 13mm with an average of 9.21±1.97mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, found that the maximum width of ROC was 13.09±1.99mm.

7) MINIMUM WIDTH OF THE RIGHT OCCIPITAL CONDYLE

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, found that the minimum width of ROC was 5.71±1.61mm.

8) LENGTH OF THE LEFT OCCIPITAL CONDYLE (LOC)

Sait Naderi et al [49](2005) in their study of 202 human dry skulls, reported that the length of the LOC was 23.2mm.

Emine et al [10](2006) studied about 59 human dry skulls and stated that the length of the LOC was in the range of 18.2mm to 31.1mm with an average of 24.6±2.5mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls reported that the maximum length of LOC was in the range of 18.8 mm to 30.9mm with an average of 24.7±2.7mm.

Mehmet Asim Ozer et al [34](2011) studied 144 adult dry skulls and recorded that the length of LOC was 23.92±3.3mm.

Tien V et al [56](2011) in their study of 170 cranial CT scans reported that the mean length of LOC was 22.5±2.2mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the mean length of the LOC was 23.3±2.6mm.

Bello S.S et al [4](2013) studied about 240 cranial CT scans and reported that the LOC mean length was 23.7±2.8mm.

Fathy Ahmed Fetouh et al [12](2013) studied about 100 adult dry skulls and recorded that the mean maximum length of LOC was in the range of 18.3mm to 29.4mm with an average of 23.75mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, found that the length of LOC was 25.60±2.70mm.

Pooja Gangrade et al [44](2013) studied 100 adult dry skulls and recorded that the mean length of LOC of male and female were 26.12mm and 22.18mm respectively.

Parvindokht Bayat et al [39](2014) in their study of 50 adult dry skulls, reported that the mean maximum length of LOC varied from 10mm to 26mm with an average of 19.28±3.57mm.

9) MAXIMUM WIDTH OF THE LEFT OCCIPITAL CONDYLE

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls reported that the width of the LOC was 10.6mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the width of the LOC was from 10.1mm to 17.2mm with an average of 13±1.5mm.

Emel AVCL et al [9](2011) in their study of 30 dry skulls reported that the maximum width of LOC was in the range of 9.3 mm to 15.3 mm with an average of 12.4±1.5mm.

Mehmet Asim Ozer et al [34](2011) studied 144 adult dry skulls and recorded that the width of LOC was 10.7±2.3mm.

Tien V et al [56](2011) in their study of 170 cranial CT scans reported that the mean width of LOC was 11.2±1.5mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the mean width of the LOC was 16.4±1.6mm.

Bello S.S et al [4](2013) studied about 240 cranial CT scans and reported that the mean width of LOC was 12.7± 1.4mm.

Fathy Ahmed Fetouh et al [12](2013) studied about 100 adult dry human skulls and recorded that the mean maximum width of LOC varied from 10.2mm to 16.8mm with an average of 13.62mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, found that the maximum width of LOC was 13.01±1.98mm.

Parvindokht Bayat et al [39](2014) in their study of 50 adult dry skulls, reported that the mean maximum width of LOC varied from 6mm to 13mm with an average of 9.40±1.8mm.

10) MINIMUM WIDTH OF THE LEFT OCCIPITAL CONDYLE

K. Natsis et al [31](2013) in their study of 143 adult human dry skulls, found that the minimum width of LOC was 6.25±1.76mm.

11) BICONDYLAR DISTANCE (BCD)

Daniel J et al [7](2001) in their study of 522 adult dry skulls, reported that the BCD of black male and female were 49.6mm and 47.3mm respectively and white male and female were 51.9mm and 49.8mm respectively.

Gagandeep Singh et al [15](2012) studied about 50 skulls (26 males and 24 females). They reported that the BCD of the FM of male and female were 46.73mm and 44.29mm respectively.

12) ANTERIOR INTERCONDYLAR DISTANCE (AICD)

Daniel J et al [7](2001)in their study of 522 adult dry skulls, reported that the AICD of black male and female were 20.1mm and 18.6mm respectively and white male and female were 20.9mm and 19.2mm respectively.

Aynur Emine Cicekcibasi et al [2](2004) studied about 60 skulls (34 male and 26 female). They reported that the AICD of male and female were 16.09±1.93mm and 14.68±1.80mm respectively.

Sati Naderi et al [49](2005) in their study of 202 adult human dry skulls, reported that the AICD was 21.0mm.

Emine et al [10](2006) studied about 59 human adult dry skulls and reported that the AICD was in between 15mm and 32mm with an average of 22.6±3.9mm.

Mehmet AsimOzer et al [34](2011) studied 144 adult dry skulls and reported that the mean AICD was 20.9 ±3.6mm.

di Vasudha V. Saralaya et al [8](2012) reported that the mean AICD was 18.7mm.

Gagandeep Singh et al [15](2012) studied about 50 skulls (26 male and 24 female). They reported that the AICD of male and female were 14.88mm and 14.33mm respectively.

Fathy Ahmed Fetouh et al [12](2013) studied about 100 adult dry human skulls and recorded that the AICD varied from 11.5mm to 25.5mm with an average of 20.64mm.

K. Natasis et al [31](2013) in their study of 143 adult human dry skulls, found that the mean AICD was 19.30±3.25mm.

Pooja Gangrade et al [44](2013) studied 100 adult dry skulls and recorded that the mean AICD of male and female were 18.32mm and 15.44mm respectively.

Parvindokht Bayat et al [39](2014) in their study of 50 adult dry skulls, reported that the AICD was in the range of 2mm to 42mm with an average of 15.39±7.99mm.

13) POSTERIOR INTERCONDYLAR DISTANCE (PICD)

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls, reported that the PICD was in the range of 35.1mm to 48.3mm with an average of 41.6mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the PICD was in between 33mm and 50mm with an average of 44.2±3.2mm.

di Vasudha V. Saralaya et al [8](2012) studied about 70 adult human dry skulls.They reported that the mean PICD was 38.7mm.

Gagandeep Singh et al [15](2012) studied about 50 skulls (26 male and 24 female). They reported that the maximum intercondylar distance of the FM of male and female were 26.15mm and 24.71mm respectively.

Fathy Ahmed Fetouh [12](2013) studied about 100 adult dry skulls and recorded that the PICD varied from 35.5mm to 48.5mm with an average of 41.4mm.

K. Natasis et al [31](2013) in their study of 143 dry skulls, found that the mean PICD was 51.61±5.01mm.

ParvindokhtBayat et al [39](2014) in their study of 50 adult dry skulls, reported that the PICD varied from 13mm to 44mm with an average of 35.60±8.4mm.

14) PRESENCE OF POSTERIOR CONDYLAR CANAL (PCC)

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, observed that the PCC was absent unilaterally in 27% and bilaterally in 17%.

K. Natsis et al [31](2013) in their study of 143 skulls, observed that the PCC was present in 75.5%, out of which 11.9% was present on right side, 16.1% on left side and 47.6% bilaterally.

Jatin Goda et al [24](2013) observed that the PCC was present bilaterally in 70.31% and unilaterally in 20.31 % of the 64 dry human skulls.

Ketu Chauhan et al [29](2013) studied about 82 dry human skulls and found that PCC was present in 6% on left side and bilaterally in 3.6%.

Parvindokht Bayat et al [39] (2014) in their study of 50 adult dry skulls, reported that the PCC was present in 4% on right side, 16% on left side and bilaterally in 40%.

15) PRESENCE OF SEPTUM OF THE HYPOGLOSSAL CANAL (HGC)

Muthukumar N et al [35](2005) studied 50 adult dry skulls. In 30%, HGC was divided into two compartments by a bony septum.

Nehi'r Barut et al [36](2009) studied about 56 adult dry human skulls. They found that 14 HGC (25%) were divided into two parts by a bony septum.

Emel AVCL et al [9] (2011) studied 30 adult dry skulls and found that the HGC was divided into two parts by a bony septum in 30 %.

Jasbir Kaur et al [23](2012) found division of HGC in 10.5% of male and 9.1% of female adult human skulls.

Jatin Goda et al [24](2013) observed septum of HGC in 3.12% of the 64 human adult dry skulls studied.

K. Natsis et al [31](2013) studied 143 skulls and found that the HGC septum was present in 25.5%.

Roopali et al [48](2013) stated that the septum of HGC was present in 3% of the human dry skulls studied.

Singh Rajani [50](2013) found double condylar canal in 66 dry human skulls.

Siva N R S et al [51] (2013) reported duplicated HGC in 50 dried skulls.

16) DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HYPOGLOSSAL CANAL (RHGC) AND ANTERIOR MARGIN OF RIGHT OCCIPITAL CONDYLE (ROC)

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls, reported that the distance of the intracranial end of the RHGC from the anterior tip of the ROC was 10.6mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the distance of the intracranial end of the RHGC from the anterior margin of the ROC was in the range of 8.1mm to 16.9mm with an average of 11.0±1.6mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the intracranial end of the RHGC from the anterior margin of the ROC was 11.0±1.8mm.

17) DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HYPOGLOSSAL CANAL (RHGC) AND POSTERIOR MARGIN OF RIGHT OCCIPITAL CONDYLE (ROC)

Muthukumar N et al [35](2005) studied about 50 adult human dry skulls. They found that the distance of the intracranial end of the RHGC from the posterior margin of the ROC was12.2mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the distance of intracranial end of the RHGC from the posterior margin of the ROC was in between 8.2mm and 17.4mm with an average of 12.2±2.2mm.

Nehi'r Barut et al [36](2009) studied about 56 adult dry human skulls. They found that the distance between the intracranial edge of RHGC and posterior margin of ROC was 12.5mm.

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, reported that the distance between the RHGC and posterior border of ROC varied from 7.9 mm to 12.2mm with an average of 9.8±1.1mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the distance of the intracranial end of the RHGC from the posterior margin of the ROC was 10.3±2.5mm.

18) DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HYPOGLOSSAL (LHGC) CANAL AND ANTERIOR MARGIN OF LEFT OCCIPITAL CONDYLE (LOC)

Sait Naderi et al [49](2005) in their study of 202 adult human dry skulls, reported that the distance of the intracranial end of the LHGC from the anterior tip of the LOC was 9.6mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the distance between the intracranial end of the LHGC and the anterior margin of the LOC was in the range of 8.2mm to 16.9mm with an average of 11.3±1.5mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the distance of intracranial end of the LHGC from the anterior margin of the LOC was 10.7±1.8mm.

19) DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HYPOGLOSSAL CANAL (LHGC) AND POSTERIOR MARGIN OF LEFT OCCIPITAL CONDYLE (LOC)

Emel AVCL et al [9](2011) in their study of 30 adult dry skulls, reported that the distance between LHGC and Posterior border of LOC varied from 6.6 mm to 12.2 mm with an average of 9.9±1.4mm.

Emine et al [10](2006) studied about 59 human dry skulls and reported that the intracranial end of the LHGC from the posterior margin of the LOC was in between 8.4mm and 17.6mm with an average of 12.4±2.3mm.

Nehi'r Barut et al [36](2009) studied about 56 adult dry human skulls. They found that the distance between the intracranial edge of LHGC and posterior margin of LOC was 12.6mm.

Pereira G.A et al [42](2012) in their study of 111 adult human dry skulls reported that the intracranial end of the LHGC from the posterior margin of the LOC was 11.3±2.1mm.

Embryology

Fig.3. Development of skull bones

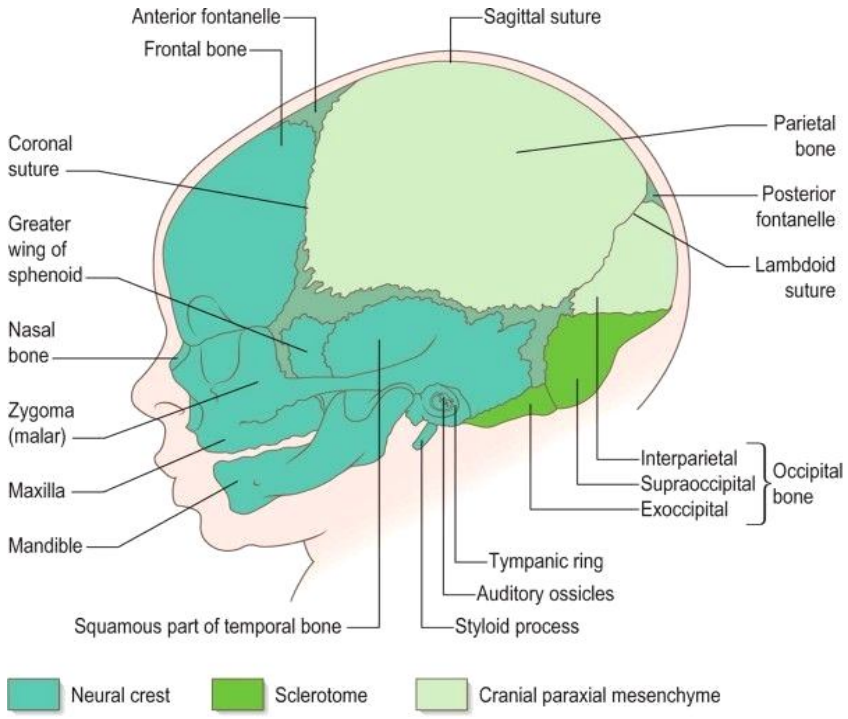
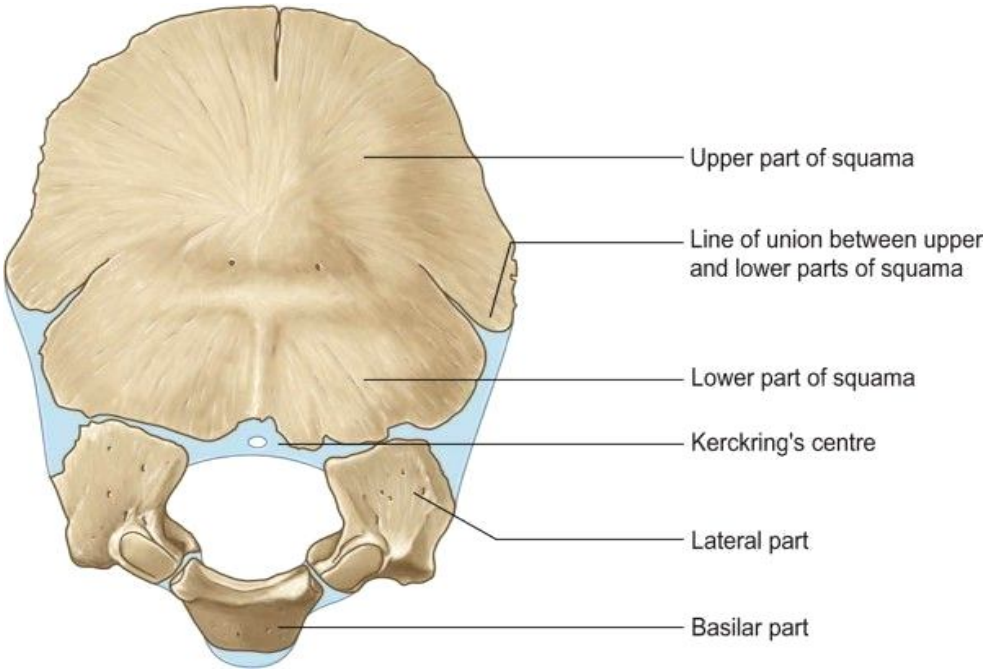


Fig.4.The Occipital bone of newborn



EMBRYOLOGY

The skull consists of two major anatomical and functional components: the neurocranium and viscerocranium. The neurocranium forms a protective covering around the brain and viscerocranium forms the skeleton of the face.[32]

The skull develops from neural crest cells, cranial paraxial mesoderm and sclerotome(Fig.3). The neural crest cells form the whole viscerocranium and the rostral portion of neurocranium. The skull base is formed by neural crest rostral to the tip of the notochord and by sclerotome (mesoderm) in the notochordal region.

Neurocranium: It has two portions- membranous and cartilaginous portions.

Membranous neurocranium**:** It is derived from neural crest cells and paraxial mesoderm. The mesenchyme from both sources covers the brain and undergoes membranous ossification. It forms the cranial vault.

Cartilaginous neurocranium: It is also called chondrocranium. It is composed of a number of separate cartilages. The cartilages fuse and ossify by endochondral ossification and form the base of the skull.

The cartilages that are present posterior to the rostral limit of notochord arise from occipital sclerotomes formed by paraxial mesoderm. The central region of occipital sclerotomes contribute to the parachordal cartilage, which enclose the notochord and extends as a flat plate on either side of it and forms the basioccipital component of the occipital bone.[40] The exoccipital components chondrify and border the foramen magnum.

Roots of the hypoglossal nerve run between the parachordal and exoccipital cartilages. The fusion of exoccipital and parachordal components forms the foramina for hypoglossal nerve roots bilaterally.

OSSIFICATION

The occipital bone is a compound structure with respect to its origin and type of ossification (Fig.4).

The squamous part of occipital bone above the highest nuchal lines develops in membrane. It ossifies from two centres in the second foetal month. The squamous part below the highest nuchal lines ossifies from two centres which make their appearance in about the seventh week and unite immediately. The line of union of the two components of the squamous part is identifiable at birth. Kerckring's centre, which is an occasional centre for posterior margin of foramen magnum, appears at sixteenth week. The rest of the cartilage of occipital bone ossifies from five centres. During eighth week

of intauterine life, two centres each for the lateral or condylar or exoccipital parts appear. During sixth week one centre for the basilar part appears and it unites with the rest of the bone by sixth year.

The occipital bone is made up of four parts at birth – basilar, two lateral and a squamous part which fuse by cartilage and form a ring around foramen magnum. The squamous part is present posteriorly, the lateral or condylar parts are present on each side, and the basilar part or basiocciput is anterior. These names are retained for the parts of the adult bone also.[25,16]

The union of the squamous and lateral parts start from the second year. At 3-4 years, the lateral part unites with the basilar part and is completed by seventh year. The basilar part and body of the sphenoid unites by cartilage and is completely ossified by 25years.[55]

Materials and Methods

MATERIALS AND METHODS

STUDY MATERIALS:

- Hundred human adult dry skulls of unknown sex.
- 20 Computerized Tomographic Scan Images.
- Digital Vernier Calipers.
- Flexible wire.

STUDY METHODS:

1. Dry skull Method
2. Radiological Study

SPECIMEN COLLECTION:

Hundred human adult dry skulls of unknown sex available in the Institute of Anatomy, Madras Medical College were used for this study.

A. DRY SKULL METHOD:

Inclusion criteria:

1. Adult human dry skull of unknown sex.
2. Third molar tooth erupted.
3. Well defined skull sutures.

Exclusion criteria:

1. Abnormal skulls.
2. Damaged skulls.

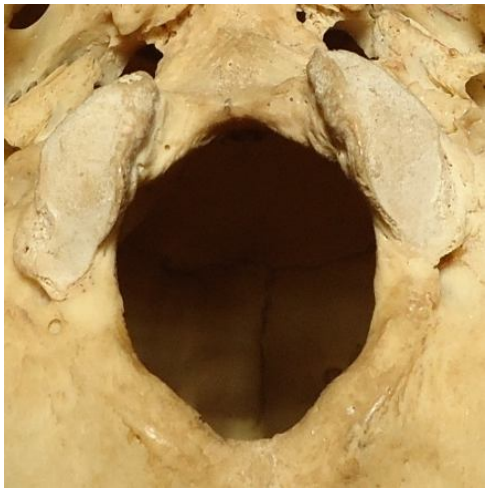
Fig.5. Skull showing various shape of Foramen magnum

OVAL

EGG SHAPE

PENTAGONAL

HEXAGONAL



ROUND

IRREGULAR

Fig 6. Protrusion of occipital condyle into the foramen magnum.

Fig 7. Presence of Posterior condylar canal

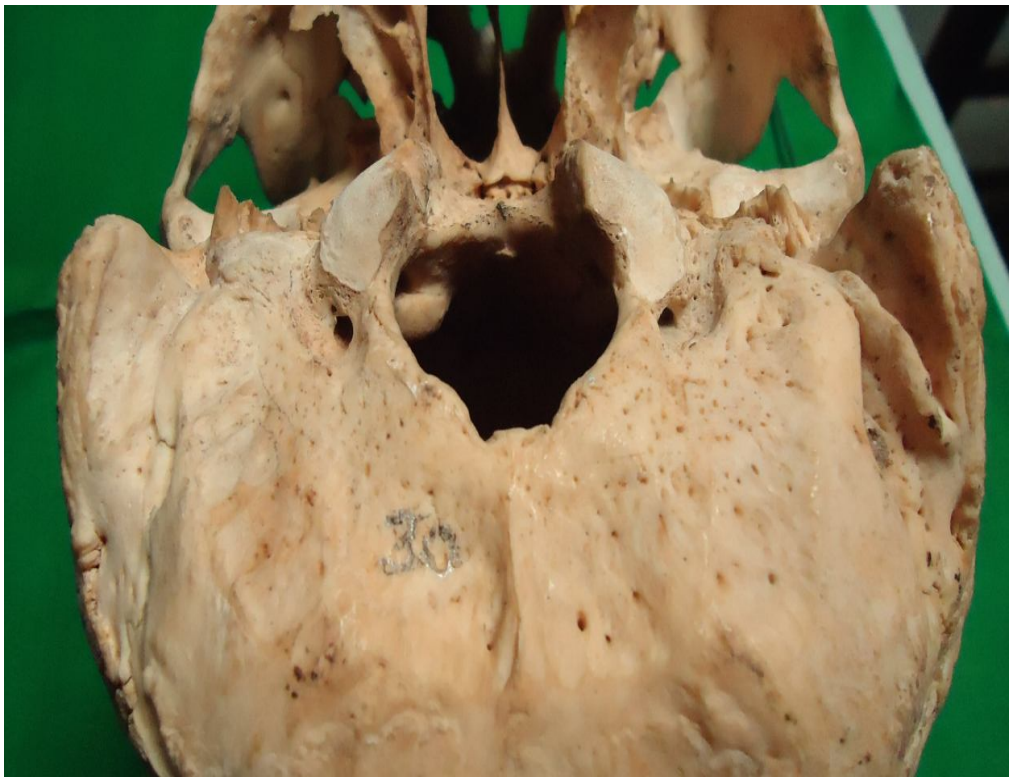


Fig 8. Presence of bilateral Posterior condylar canal

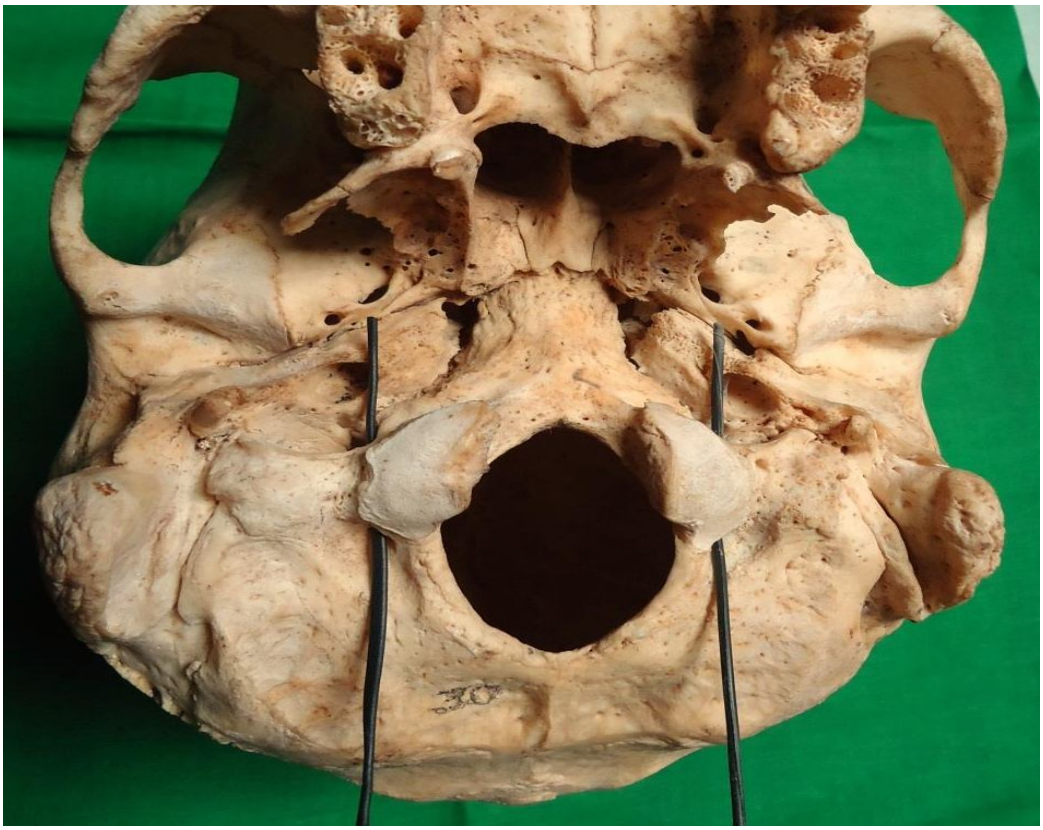
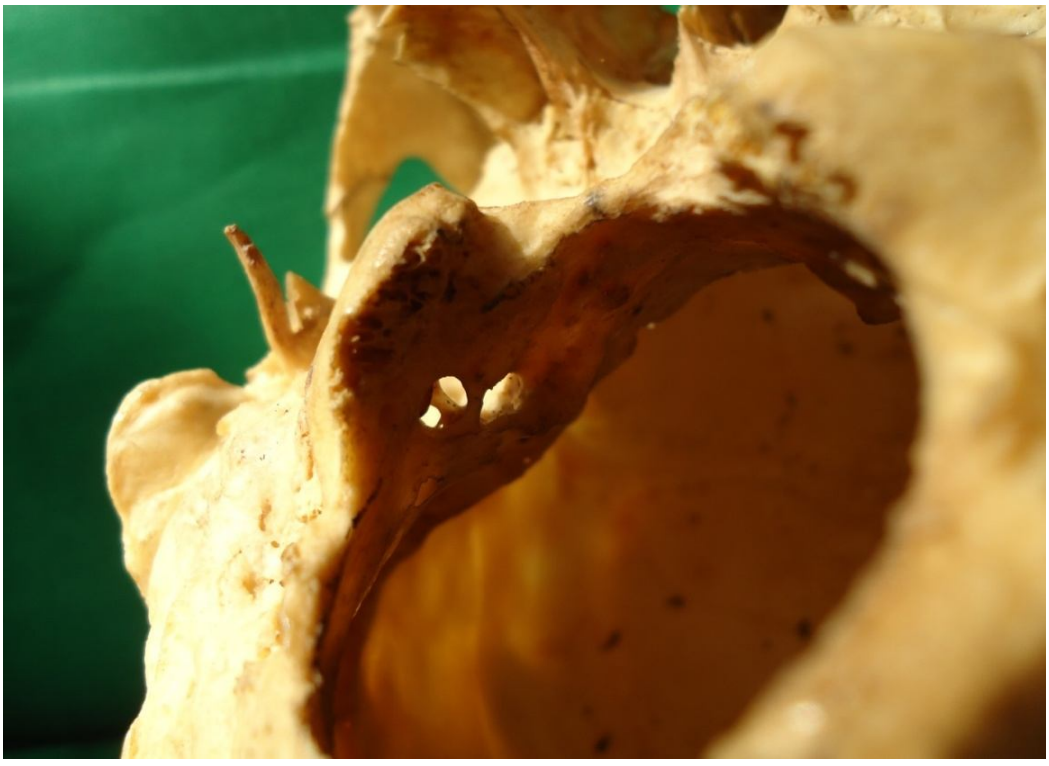
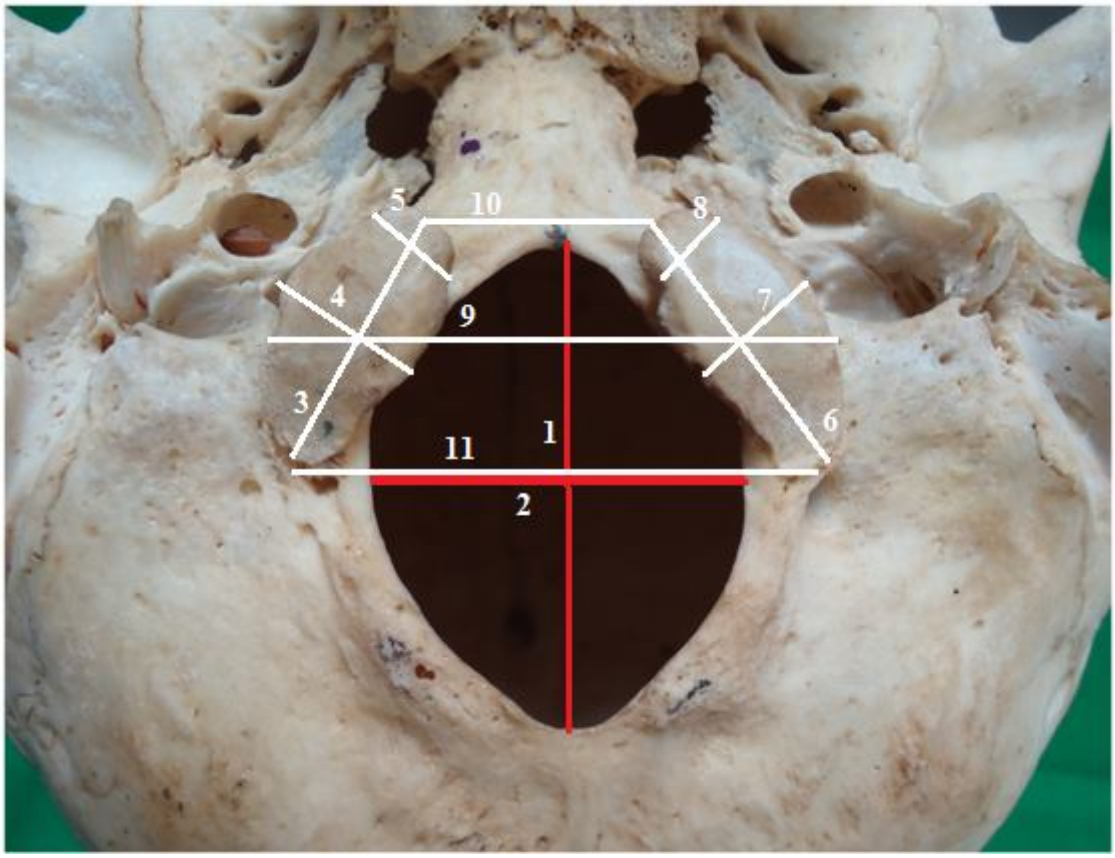


Fig.9. Presence of septum in the hypoglossal canal



Figg. 10. Illustrations showing the measurements of parameters related to Foramen magnum and occipital condyle



1). Maximum AP diameter of the FM

2) Maximum transverse diameter of the FM

3) ROC length 4) ROC maximum width 5) ROC minimum width

6) LOC length 7) LOC maximum width 8) LOC minimum width

9) BCD 10) AICD 11) PICD

Fig.11 Photograph of digital vernier caliper

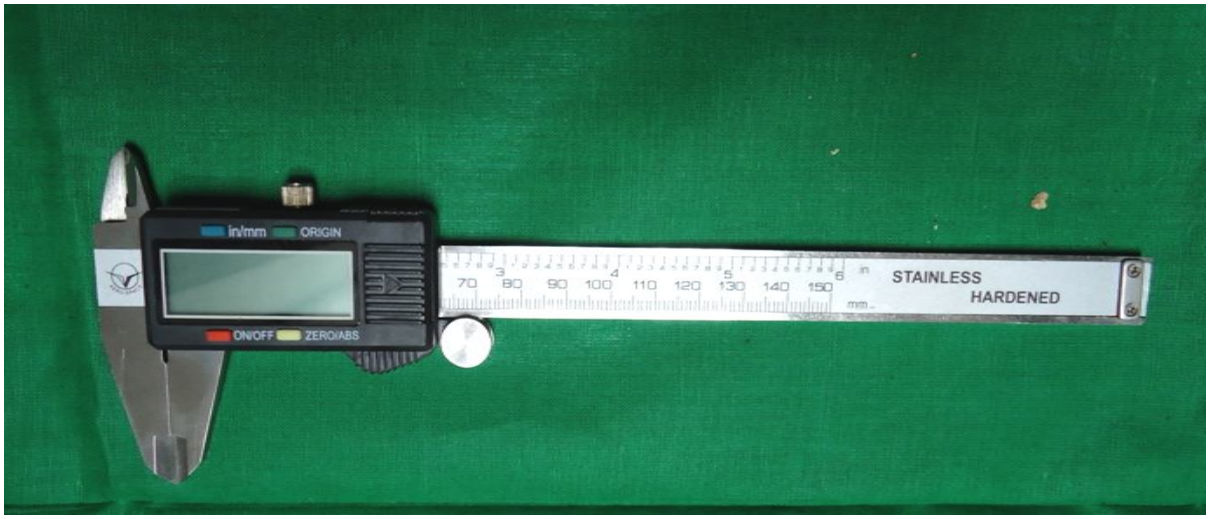


Fig.12. Maximum anteroposterior diameter of the Foramen magnum

Fig.13. Maximum transverse diameter of the Foramen magnum

Fig.14. Length of the right occipital condyle

Fig.15. Length of the left occipital condyle

Fig.16. Maximum width of the right occipital condyle

Fig.17. Maximum width of the left occipital condyle

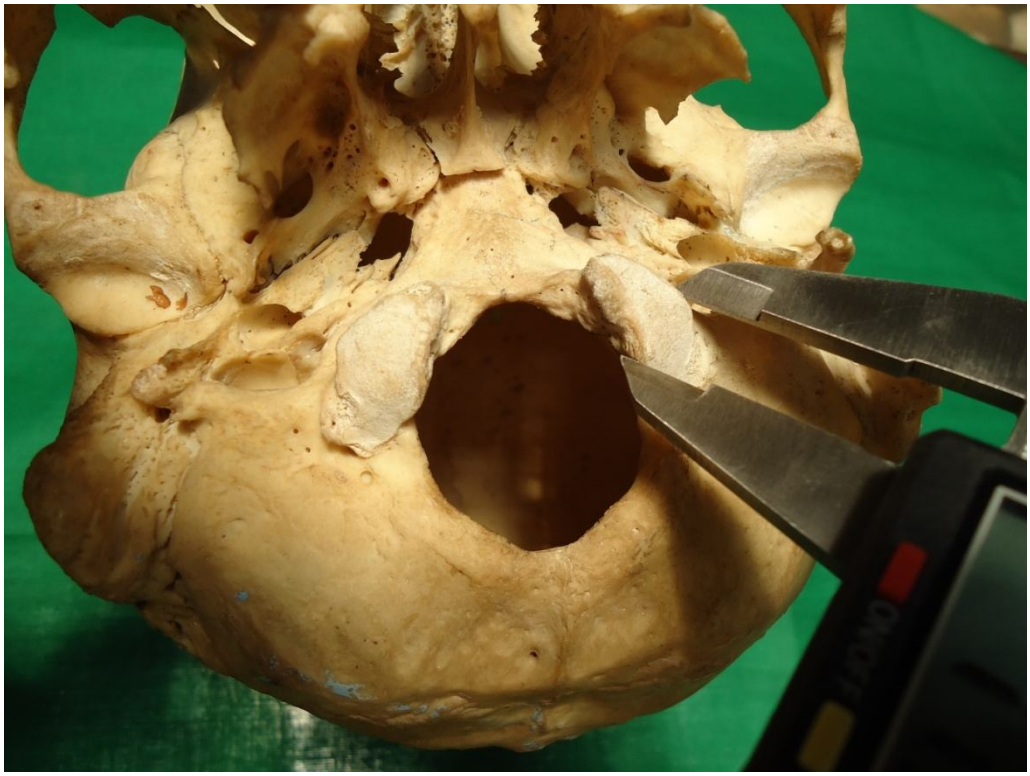


Fig.18. Minimum width of the right occipital condyle

Fig.19. Minimum width of the left occipital condyle

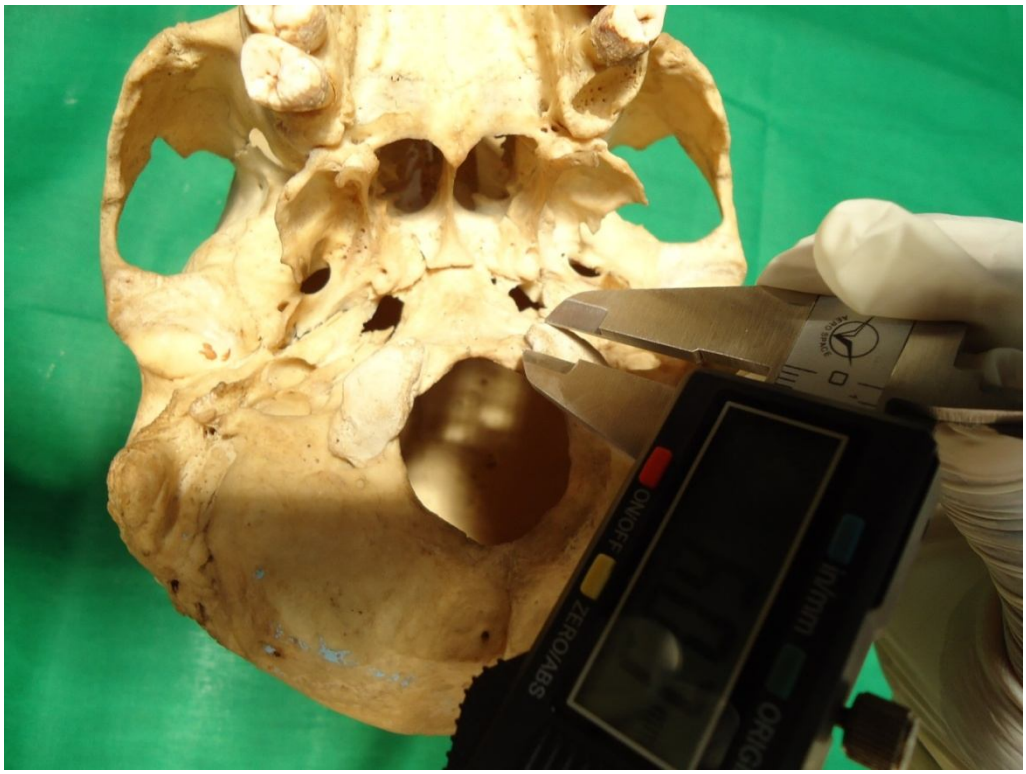


Fig.20. Bicondylar distance

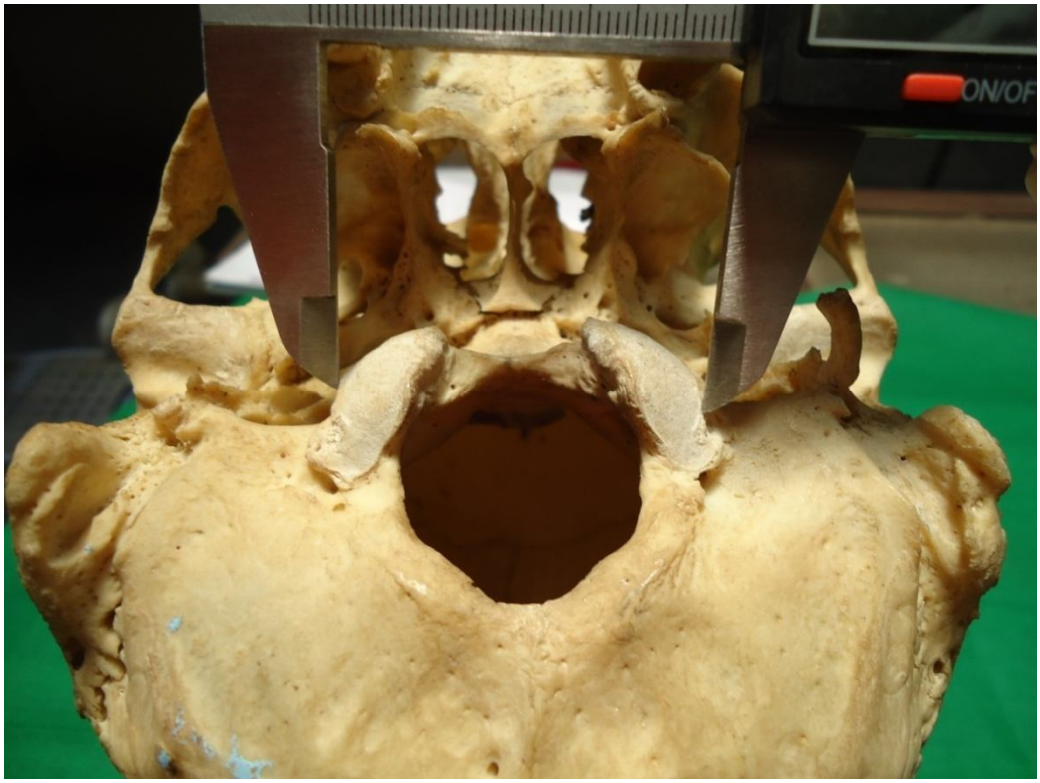


Fig.21. Anterior intercondylar distance

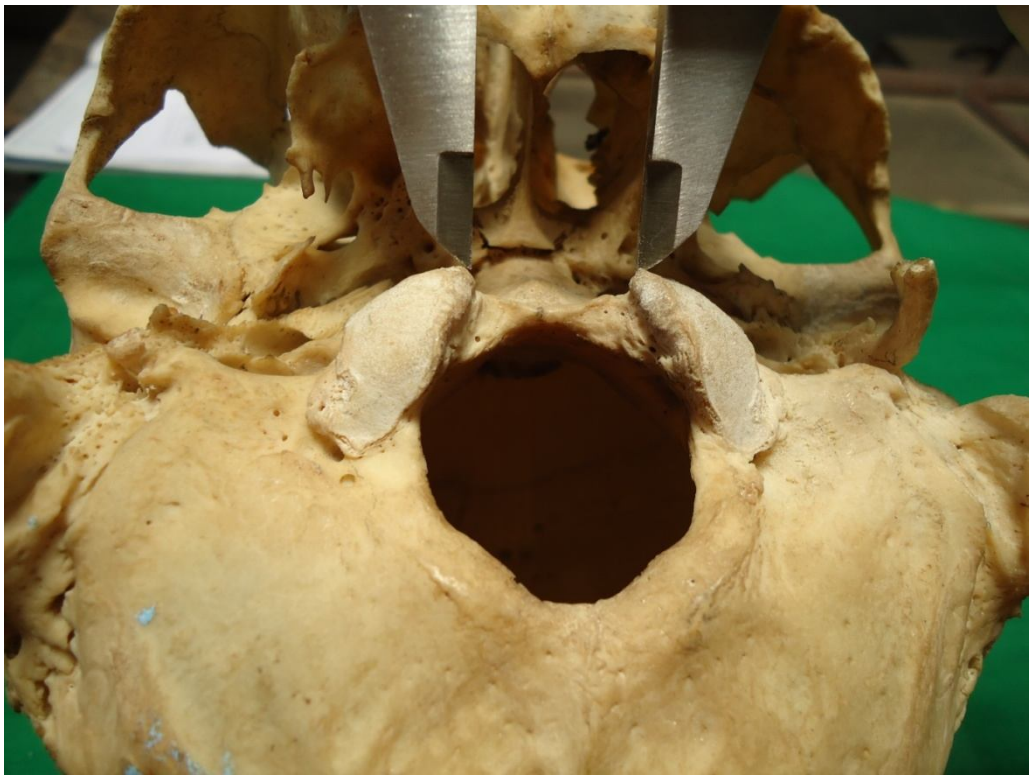


Fig.22.Posterior intercondylar distance

Fig.23 Distance between intracranial edge of RHGC and anterior margin of ROC

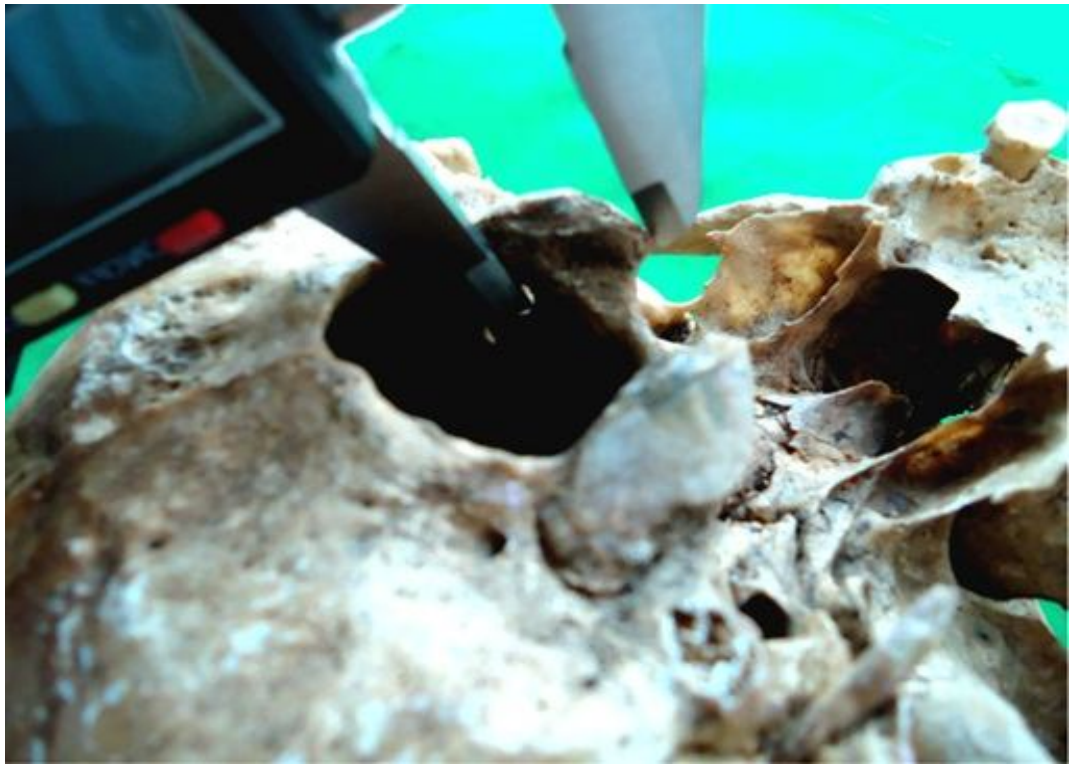
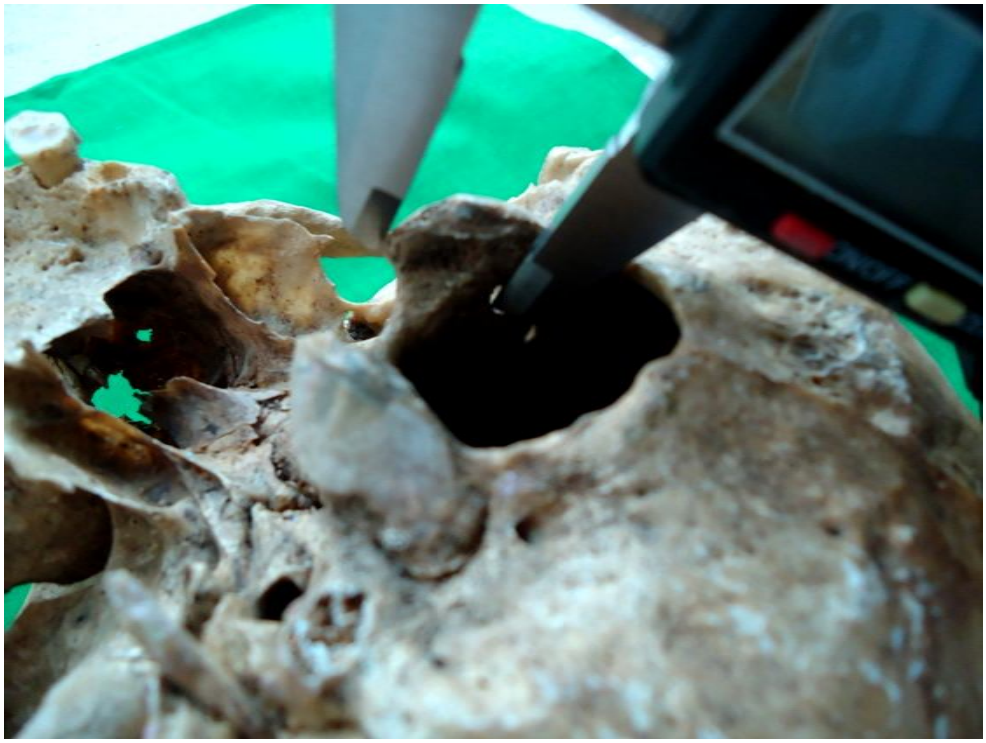


Fig.24. Distance between intracranial edge of RHGC and posterior margin of ROC

Fig.25..Distance between intracranial edge of LHGC and anterior margin of LOC



Fif.26..Distance between intracranial edge of HGC and posterior margin of LOC

The following morphological parameters were observed by gross examination.

1. Shape of the FM (Fig.5)
2. Protrusion of OC into the FM (Fig.6)
3. Presence of Posterior condylar canal (Fig.7 and 8)
4. Presence of Septum of the Hypoglossal canal. (Fig.9)

The following measurements (Fig.10) were made with the use of digital vernier calipers (Fig.11).

1) Maximum anteroposterior diameter of the FM:

Maximum distance between anterior and posterior margins measured along the midsagittal plane of the FM (Fig.12).

2) Maximum transverse diameter of the FM:

Maximum distance between the lateral margins measured along the transverse plane of the FM (Fig.13).

3) Length of the occipital condyle:

Maximum length of the OC taken along the articular surface and the parameter is recorded bilaterally (Fig.14 and 15).

4) **Maximum width of the occipital condyle :**

Maximum width of the OC taken along the articular surface perpendicular to the OC length and the parameter is recorded bilaterally(Fig.16 and 17).

5) Minimum width of the occipital condyle:

Minimum width of the OC taken along the articular surface perpendicular to the OC length and the parameter is recorded bilaterally (Fig.18 and 19).

6) Bicondylar distance:

Maximum distance between the lateral margin of right and left condylar articular facets perpendicular to the midsagittal plane (Fig.20).

7) Anterior intercondylar distance:

Distance between the anterior tips of the right and left OC perpendicular to the midsagittal plane (Fig.21).

8) Posterior intercondylar distance:

Distance between the posterior tips of the right and left OC perpendicular to the midsagittal plane (Fig. 22).

9) Distance between intracranial edge of Hypoglossal canal and anterior margin of OC:

Distance between intracranial edge of HGC and anterior margin of the corresponding occipital condyle and the parameter is recorded bilaterally (Fig.23 and 24).

10) Distance between intracranial edge of Hypoglossal canal and posterior margin of the OC:

Distance between intracranial edge of HGC and posterior margin of the corresponding occipital condyle and the parameter is recorded bilaterally (Fig.25 and 26).

B. RADIOLOGICAL STUDY:

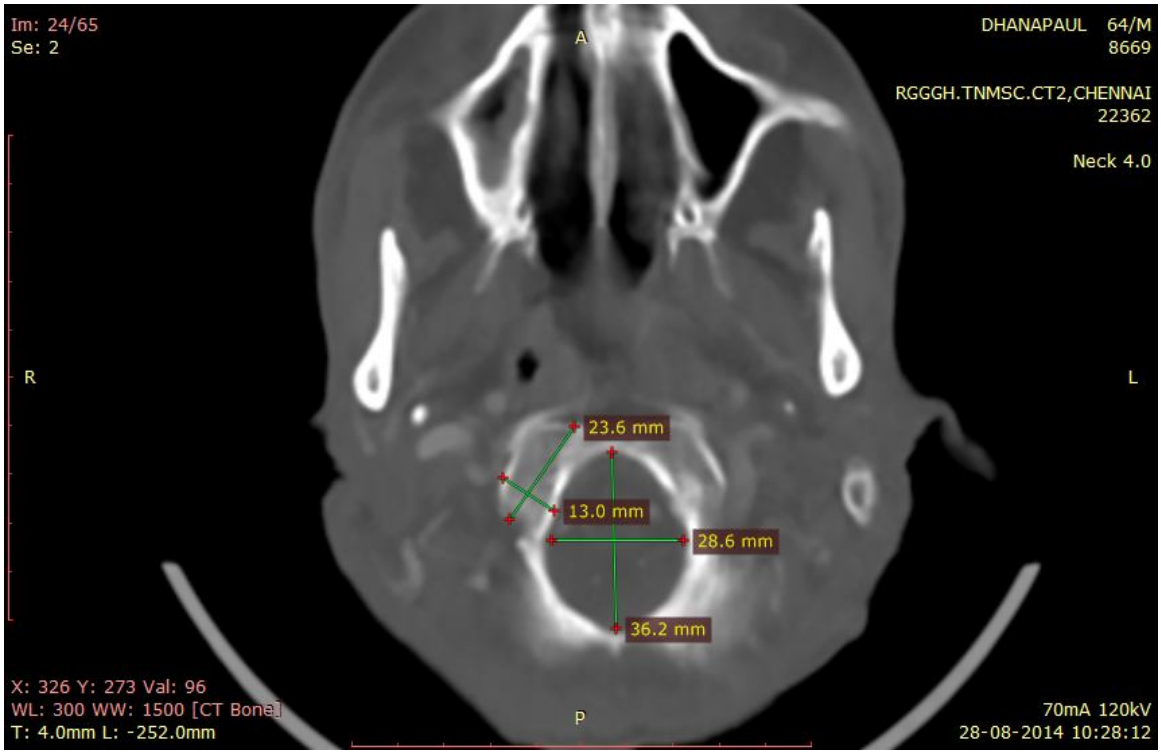
1. Adult Clinical 4 slice cranial CT scan.

The CT images from the archives of the Barnard Institute of Radiology attached to Rajiv Gandhi Government General Hospital and Research Institute were used for the study. Images of patients who had their CT pictures taken for various ailments in head and neck were used for analysis of foramen magnum.

CT scans were performed using a Toshiba Asterion 4 machine in the Barnard Institute of Radiology. Sequential 5 mm continuous cross sectional slices was made. The scan was done using 200 mA and 80-120 technique.

Fig 27. C.T Scan image of base of skull showing Foramen magnum

Fig 28.C.T Scan showing the measurement of parameters of FM and OC



The images were digitized and stored on the Picture Archiving Communication System which was later retrieved for measurement of parameters. The system was incorporated with image enhancement and manipulation tools. The software also had a sensitive measuring tool.

From CT images, parameters were measured (Fig 27 and 28). Some of the parameters were measured bilaterally.

Observation

OBSERVATIONS

100 adult dry human skulls were studied and the observations were grouped under morphological and morphometric parameters.

TABLE.1 SHOWING THE PERCENTAGE OF FM OF DIFFERENT TYPES IN DRY SKULL

Sl. No	Shape of the foramen magnum	Number of skulls N=100	Percentage
1)	Oval	40	40%
2)	Egg shape	22	22%
3)	Round	13	13%
4)	Pentagonal	3	3%
5)	Hexagonal	7	7%
6)	Others	15	15%

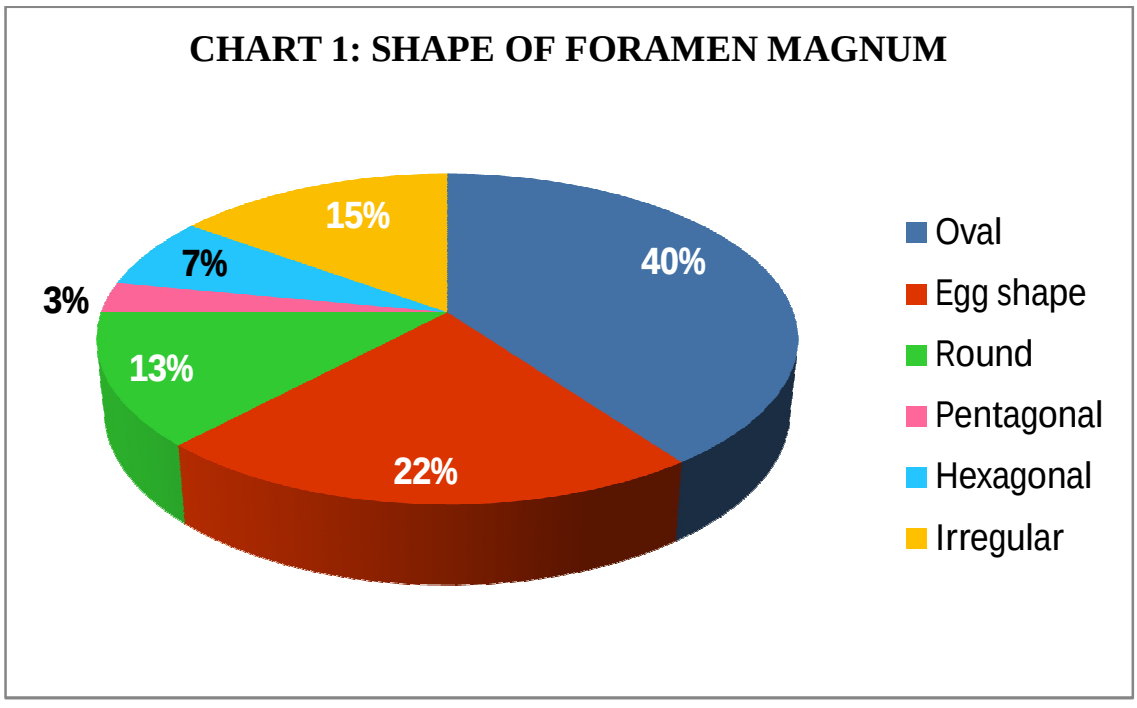


TABLE.2: ANTEROPOSTERIOR DIAMETER OF THE FORAMEN MAGNUM (FM) IN DRY SKULLS

STATISTICAL DATA	AP DIAMETER OF FM IN DRY SKUL (in mm)
No. of skulls	100
Minimum	24.64
Maximum	39.89
Mean	35.12
S.D	02.65

The whole range of values is shown in the histogram with a bell shaped curve below.

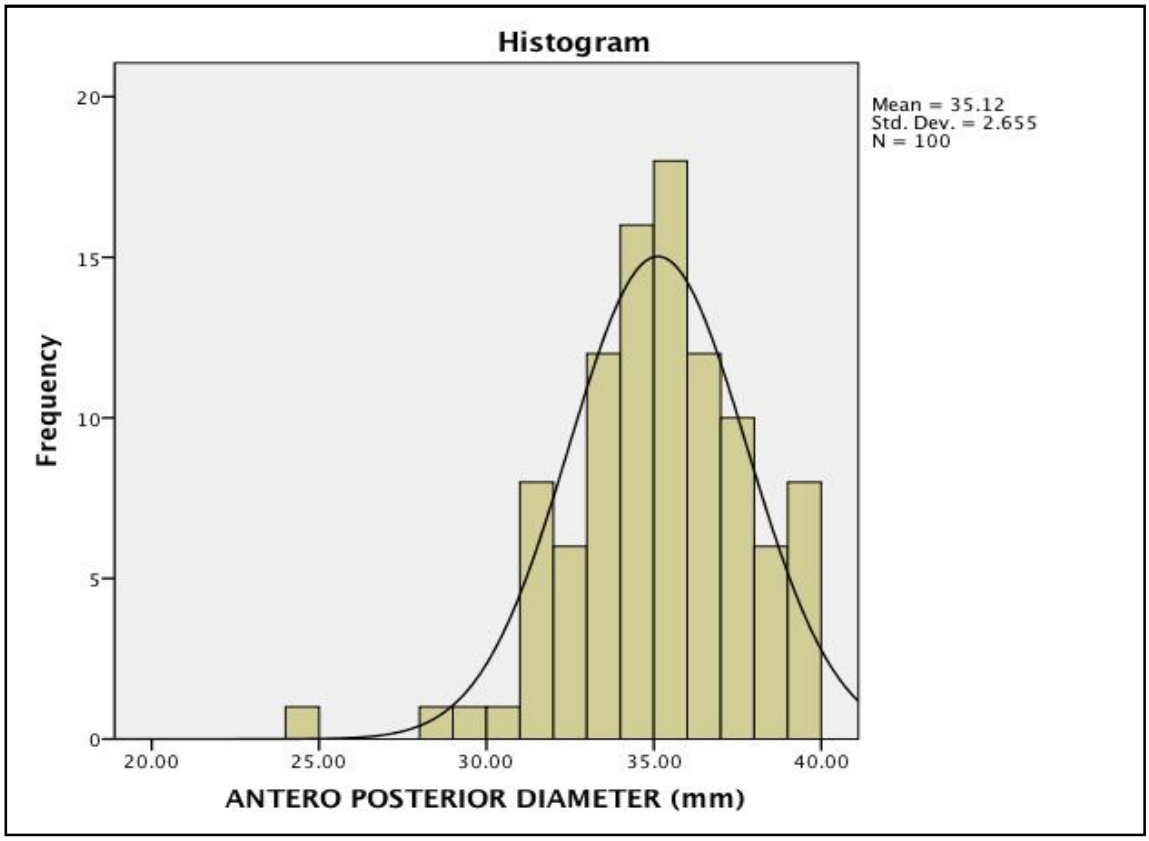


TABLE.3: MAXIMUM TRANSVERSE DIAMETER OF THE FORAMEN MAGNUM (FM) IN DRY SKULL

STATISTICAL DATA	TRANSVERSE DIAMETER OF FM IN DRY SKULLS (in mm)
No. of skulls	100
Minimum	24.01
Maximum	35.98
Mean	29.03
S.D	2.15

The whole range of values is shown in the histogram with a bell shaped curve below.

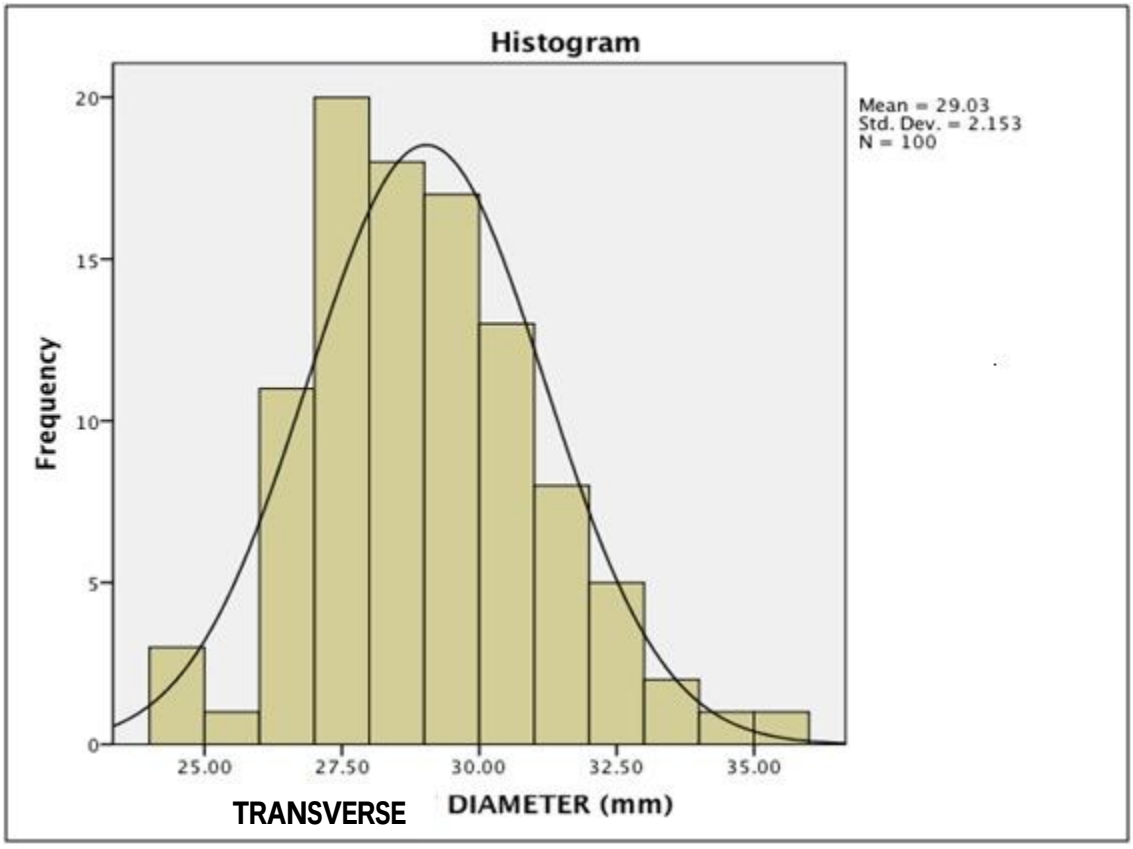


TABLE.4: MAXIMUM ANTEROPOSTERIOR DIAMETER OF THE FORAMEN MAGNUM IN CT SCAN

STATISTICAL DATA	AP DIAMETER OF FM IN CT SCAN (in mm)
No. of skulls	20
Minimum	33.13
Maximum	36.54
Mean	35.03
S.D	0.95

The whole range of values is shown in the histogram with a bell shaped curve below.

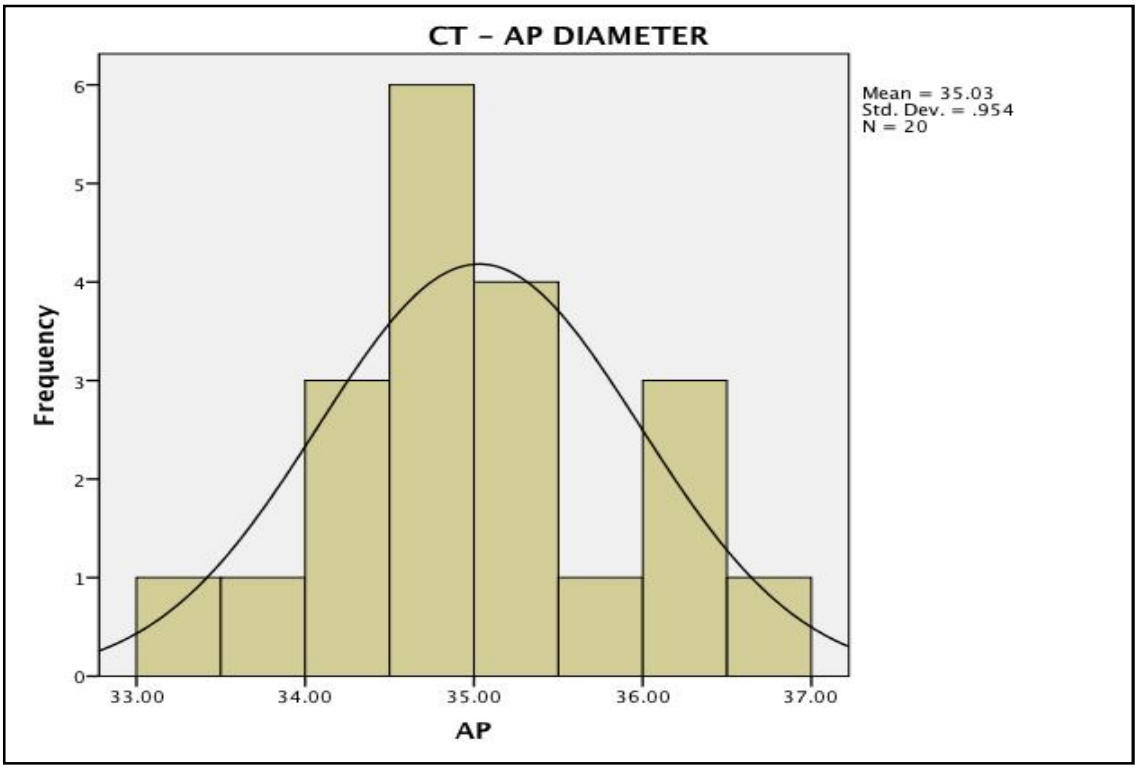


TABLE.5: MAXIMUM TRANSVERSE DIAMETER OF THE FORAMEN MAGNUM IN CT SCAN

STATISTICAL DATA	TRANSVERSE DIAMETER OF FM IN CT SCAN (in mm)
No. of skulls	20
Minimum	27.65
Maximum	28.04
Mean	28.79
S.D	1.17

The whole range of values is shown in the histogram with a bell shaped curve below.

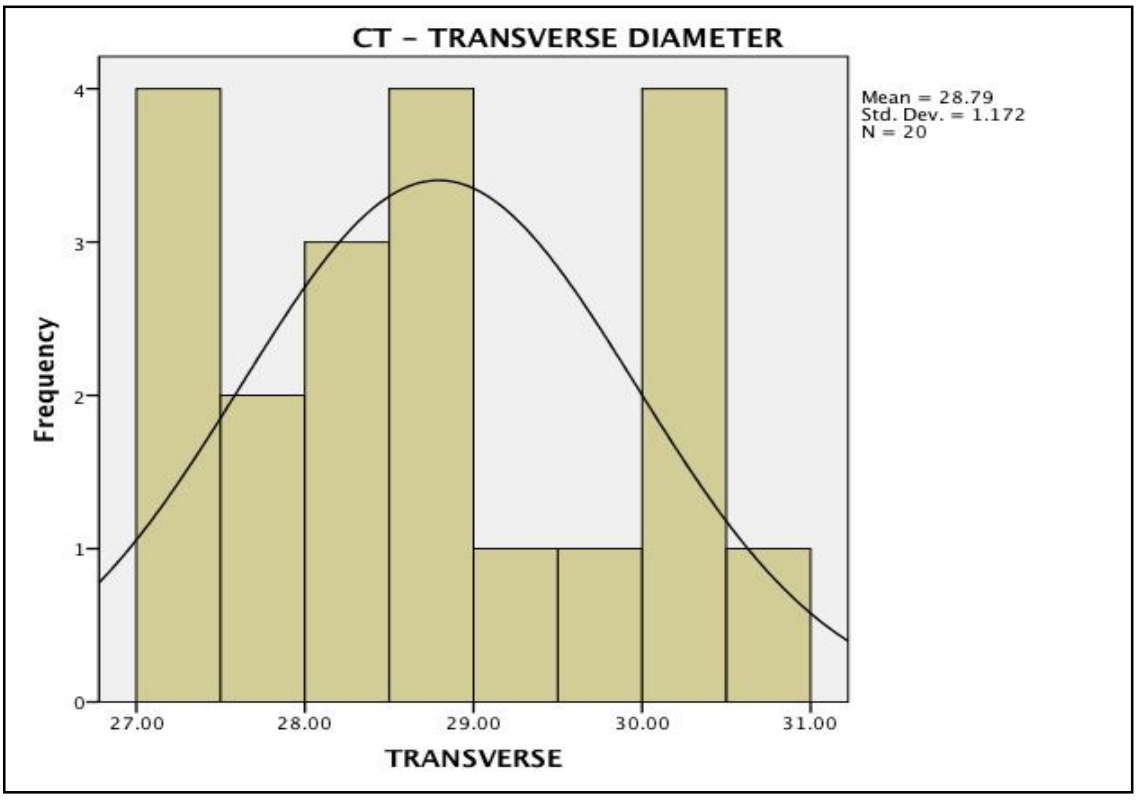


TABLE.6: COMPARISON OF ANTEROPOSTERIOR AND TRANSVERSE DIAMETER OF FM IN DRY SKULLS WITH RADIOLOGICAL STUDY

STATISTICAL DATA	ANTEROPOSTERIOR DIAMETER OF FM		TRANSVERSE DIAMETER OF FM	
	DRY SKULL	CT SCAN	DRY SKULL	CT SCAN
No. of skulls	100	20	100	20
Mean	35.12	35.03	29.03	28.79
S.D	02.65	0.95	2.15	1.17

The mean anteroposterior and transverse diameter of FM in dry skull study were greater than those in CT scan**.**

PRESENCE OF PROTRUSION OF OCCIPITAL CONDYLE

Of the 100 skulls examined, protrusion of OC was found in 20 skulls and was absent in 80 skulls

TABLE:7 PROTRUSION OF THE OCCIPITAL CONDYLE

Sl.No	PROTRUSION OF OCCIPITAL CONDYLE	NUMBER OF SKULLS (N=100)	PERCENTAGE
1)	Present	20	20%
2)	Absent	80	80%

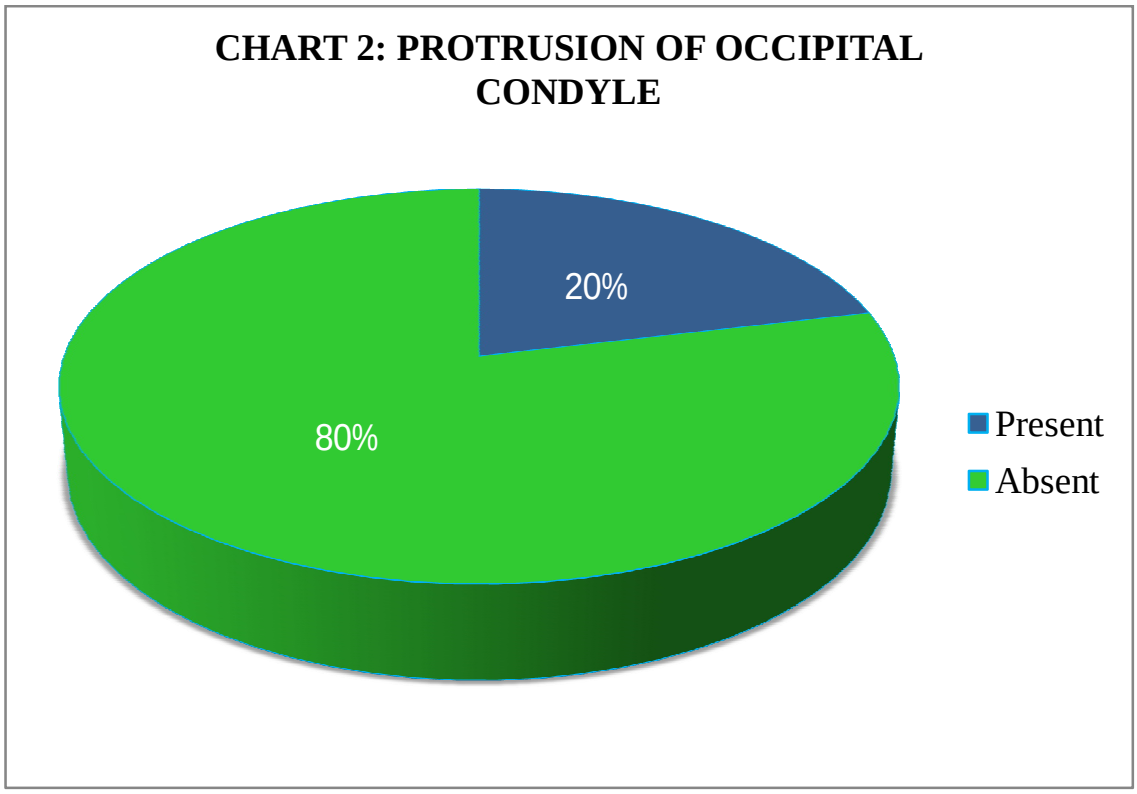


TABLE.8: LENGTH OF THE RIGHT OCCIPITAL CONDYLE(ROC)

STATISTICAL DATA	ROC - LENGTH (in mm)
No. of skulls	100
Minimum	18.16
Maximum	32.68
Mean	23.85
S.D	2.12

The whole range of values is shown in the histogram with a bell shaped curve below.

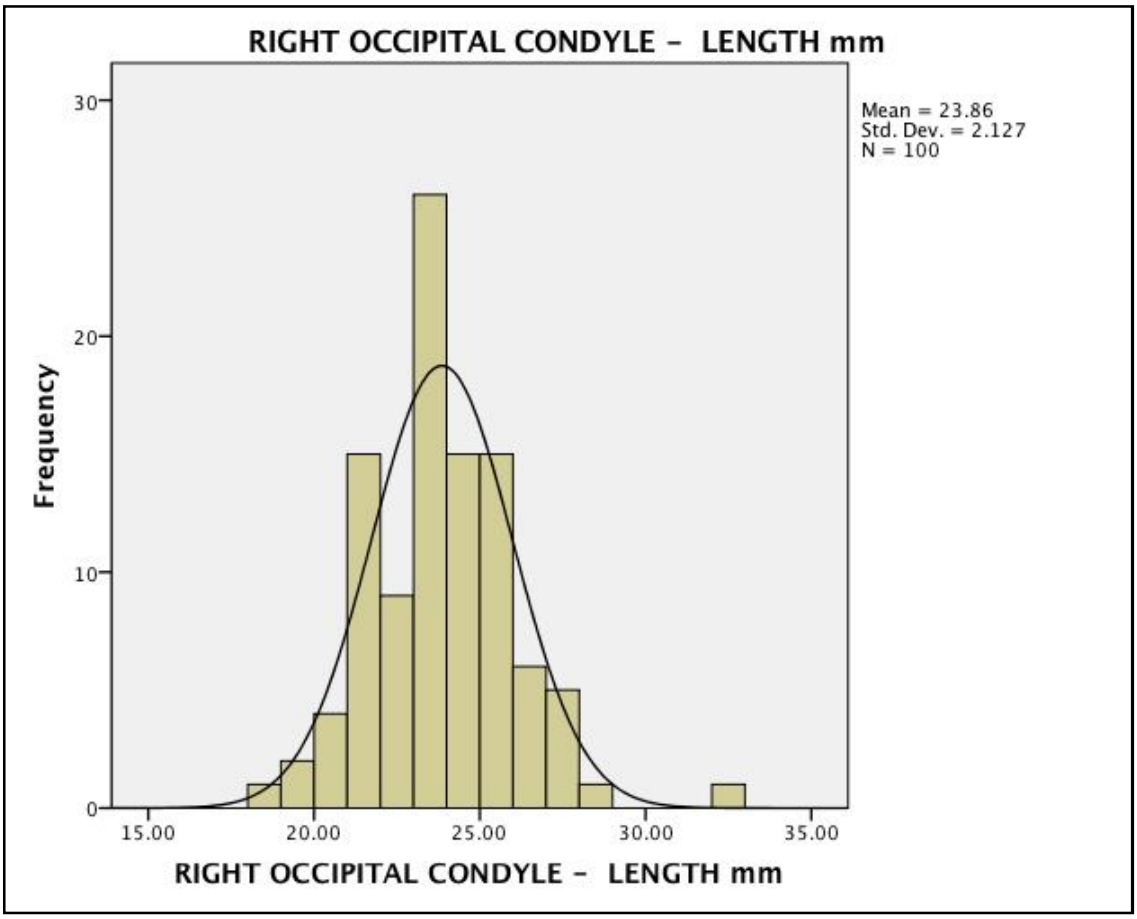


TABLE.9: MAXIMUM WIDTH OF THE ROC

STATISTICAL DATA	ROC - MAXIMUM WIDTH (in mm)
No. of skulls	100
Minimum	9.76
Maximum	16.19
Mean	13.29
S.D	±1.36

The whole range of values is shown in the histogram with a bell curve below.

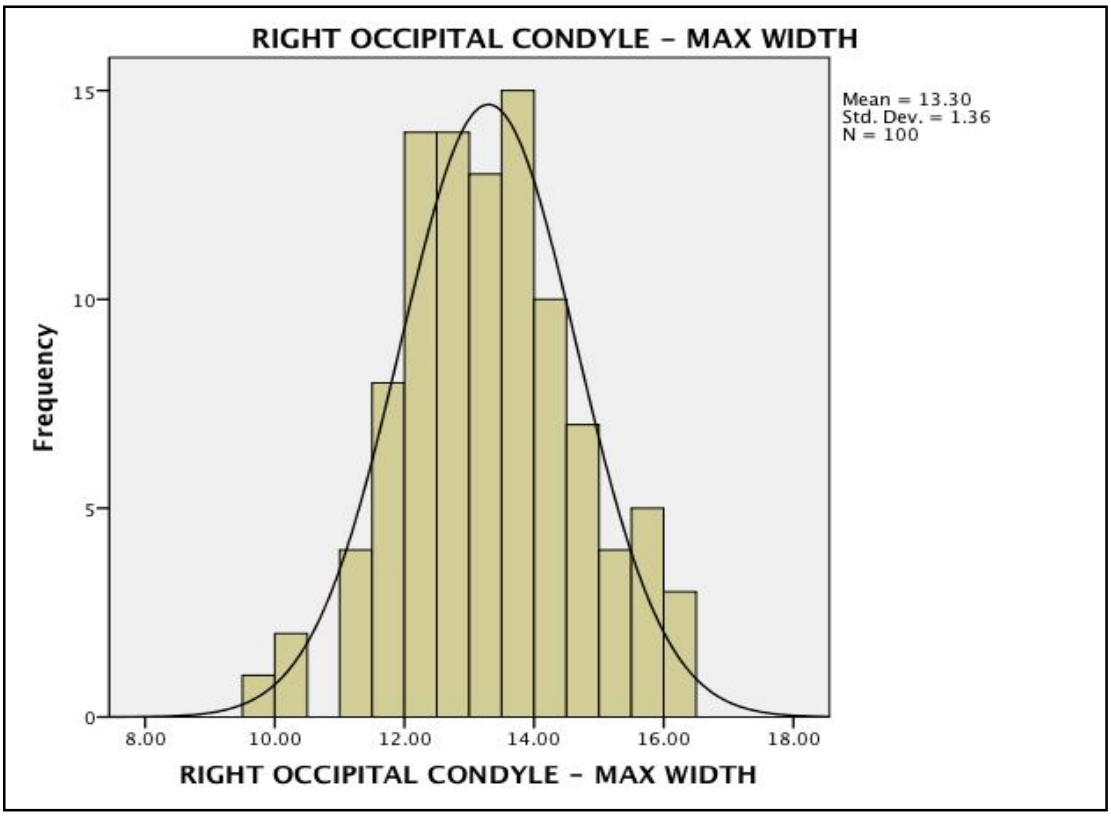


TABLE 10: MINIMUM WIDTH OF THE ROC

STATISTICAL DATA	ROC - MINIMUM WIDTH (in mm)
No. of skulls	100
Minimum	3.25
Maximum	10.62
Mean	6.86
S.D	±1.34

The whole range of values is shown in the histogram with a bell shaped curve below.

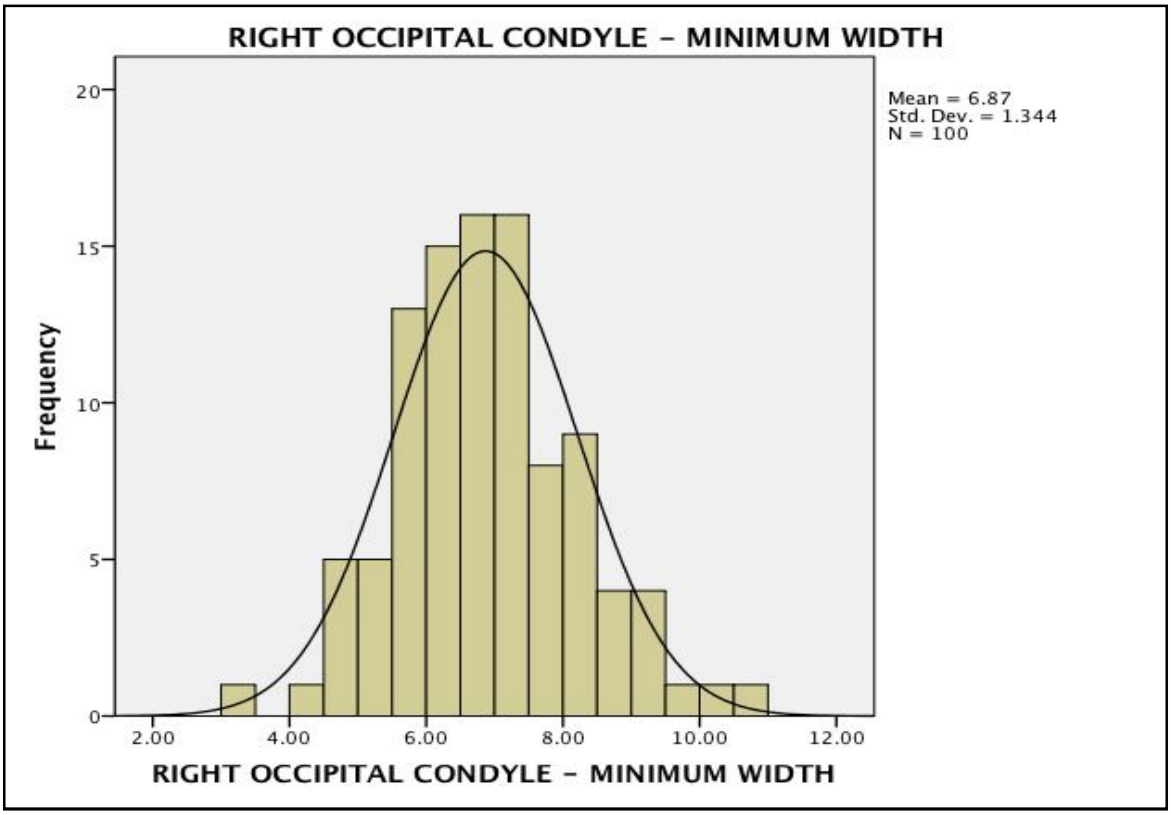


TABLE 11: LENGTH OF THE LEFT OCCIPITAL CONDYLE(LOC)

STATISTICAL DATA	LOC - LENGTH (in mm)
No. of skulls	100
Minimum	17.25
Maximum	32.02
Mean	23.77
S.D	±2.29

The whole range of values is shown in the histogram with a bell shaped curve below.

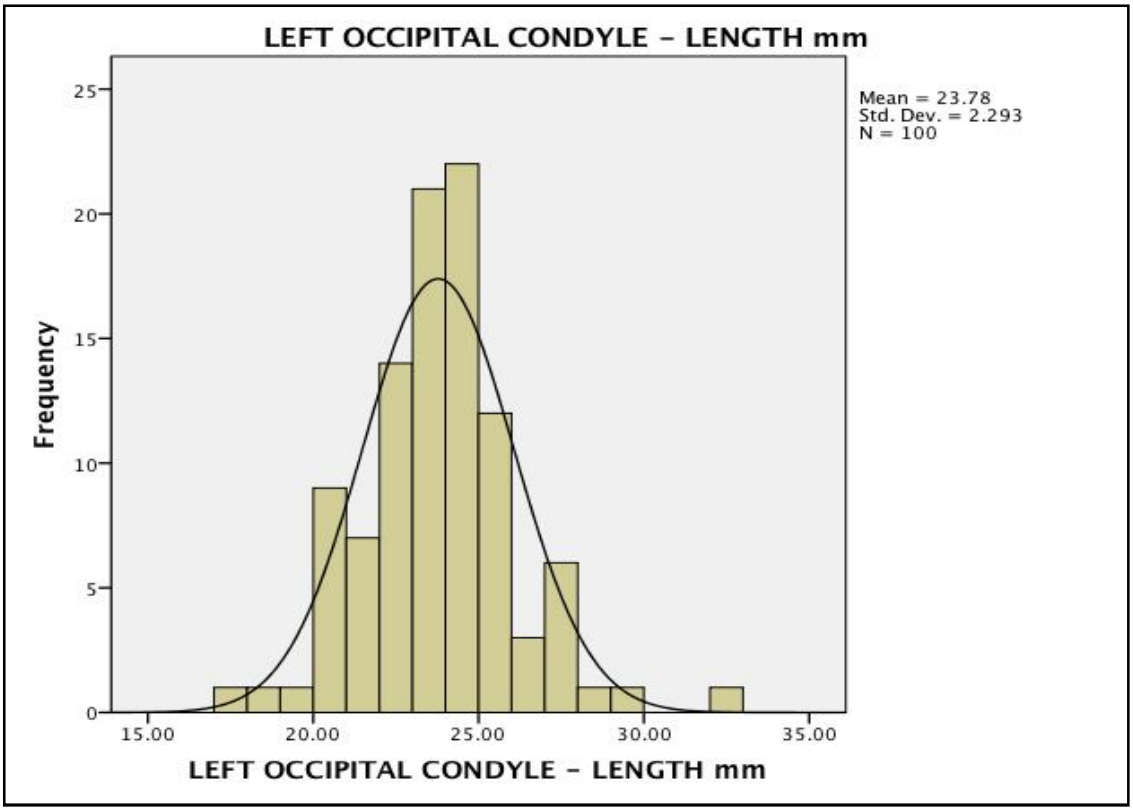


TABLE 12: MAXIMUM WIDTH OF THE LOC

STATISTICAL DATA	LOC - MAXIMUM WIDTH (in mm)
No. of skulls	100
Minimum	9.85
Maximum	16.78
Mean	13.44
S.D	±1.41

The whole range of values is shown in the histogram with a bell shaped curve below.

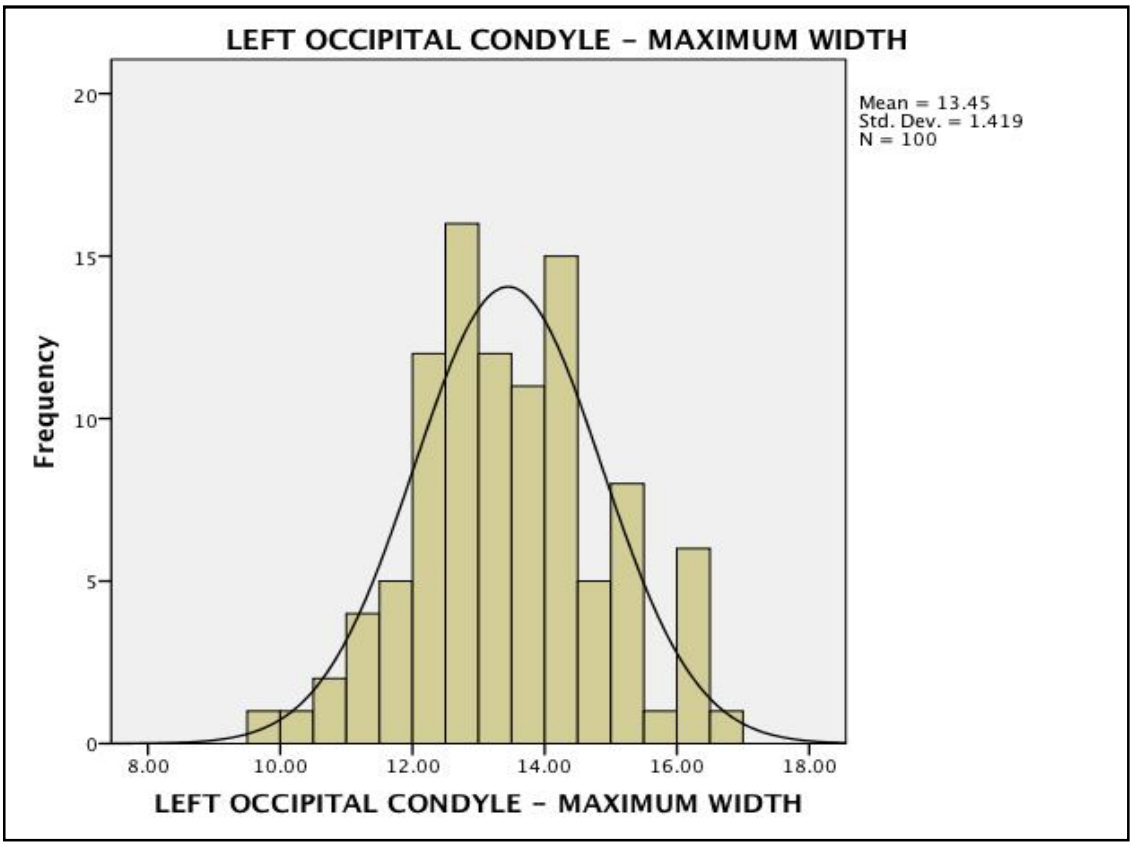


TABLE 13: MINIMUM WIDTH OF THE LOC

STATISTICAL DATA	LOC - MINIMUM WIDTH (in mm)
No. of skulls	100
Minimum	4.72
Maximum	10.32
Mean	7.04
S.D	±1.26

The whole range of values is shown in the histogram with a bell shaped curve below.

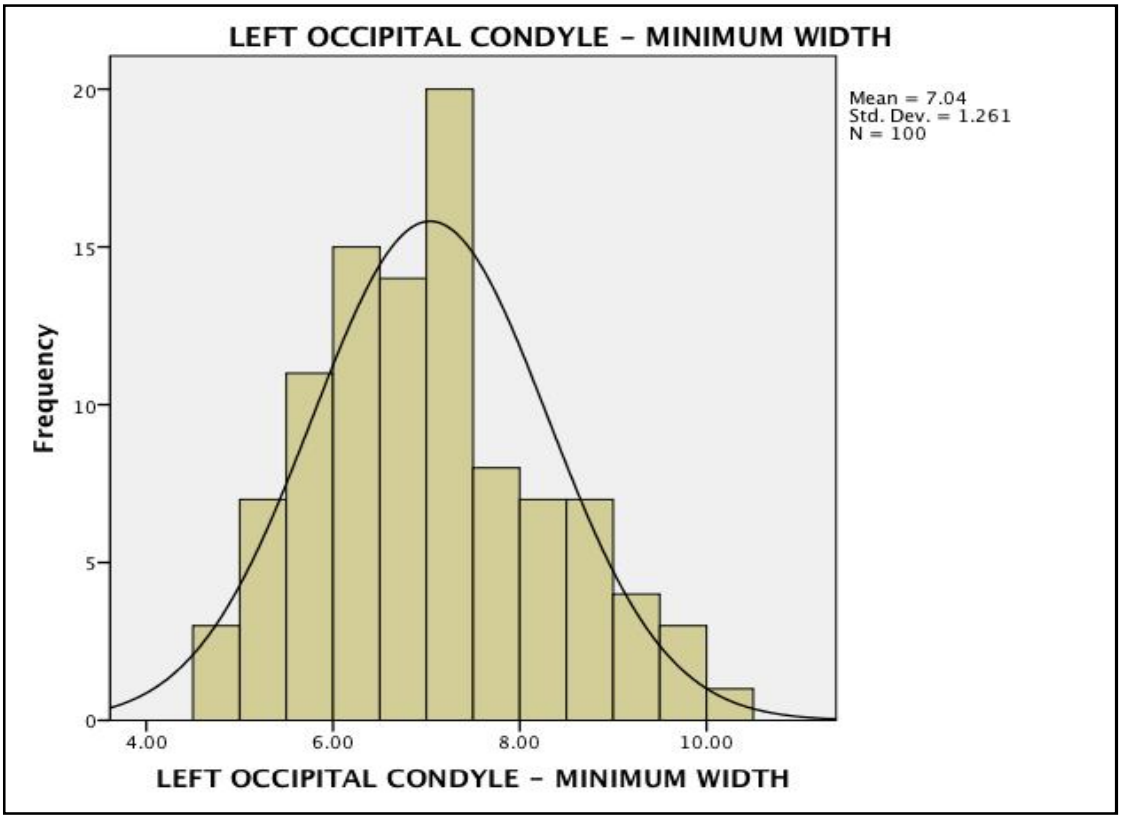


TABLE 14: COMPARISON BETWEEN MEAN LENGTH, MAXIMUM WIDTH AND MINIMUM WIDTH OF ROC AND LOC OF DRY SKULLS ALONG WITH t AND p-VALUE

STATISTICAL DATA	Side	N	Mean	SD	Std. Error Mean	t- value	p-value
LENGTH	RIGHT	100	23.85	2.12730	.21273	0.25	0.80
	LEFT	100	23.77	2.29311	.22931		
MAX WIDTH	RIGHT	100	13.29	1.35994	.13599	0.76	0.44
	LEFT	100	13.44	1.41905	.14190		
MIN WIDTH	RIGHT	100	6.86	1.34351	.13435	0.93	0.35
	LEFT	100	7.04	1.26114	.12611		

'p' value ≤ 0.05 is considered to be significant

No significant difference was observed between the right and left side of OC in the dry skulls.

TABLE 15: COMPARISON BETWEEN MEAN LENGTH AND MAXIMUM WIDTH OF ROC AND LOC OF CT SKULL

STATISTICAL DATA	ROC		LOC	
	LENGTH	BREATH	LENGTH	BREATH
No. of skulls	20	20	20	20
Minimum	22.12	11.34	22.23	11.43
Maximum	24.33	13.86	24.54	13.98
Mean	23.11	12.92	23.20	12.88
S.D	0.73	0.65	0.74	0.69

TABLE 16: COMPARISON BETWEEN MEAN LENGTH, AND MAXIMUM WIDTH OF ROC AND LOC OF CT SKULL ALONG WITH t- AND p- VALUE

STATISTICAL DATA	Side	N	Mean	SD	Std. Error Mean	t- value	p-value
LENGTH	RIGHT	20	23.1170	.73189	.16366	0.392	0.697
	LEFT	20	23.2085	.74484	.16655		
MAX WIDTH	RIGHT	20	12.9250	.65948	.14746	0.612	0.866
	LEFT	20	12.8885	.69657	.15576		

'p' value ≤ 0.05 is considered to be significant

No significant difference was observed between the right and left side of OC in cranial CT images.

TABLE 17: BICONDYLAR DISTANCE

STATISTICAL DATA	BICONDYLAR DISTANCE (in mm)
No. of skulls	100
Minimum	32.71
Maximum	53.75
Mean	47.23
S.D	3.10

The whole range of values is shown in the histogram with a bell shaped curve below.

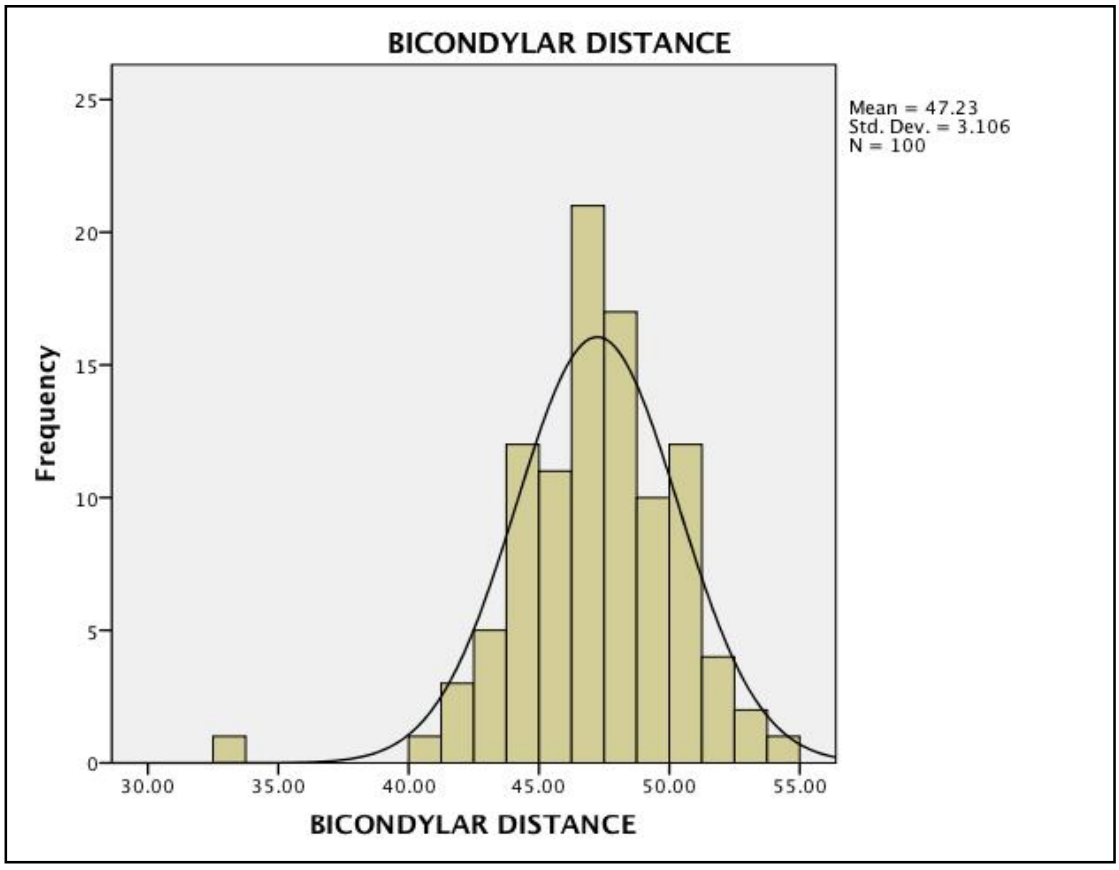


TABLE 18: ANTERIOR INTERCONDYLAR DISTANCE (AICD)

STATISTICAL DATA	AICD (in mm)
No. of skulls	100
Minimum	14.87
Maximum	25.16
Mean	20.81
S.D	2.40

The whole range of values is shown in the histogram with a bell shaped curve below.

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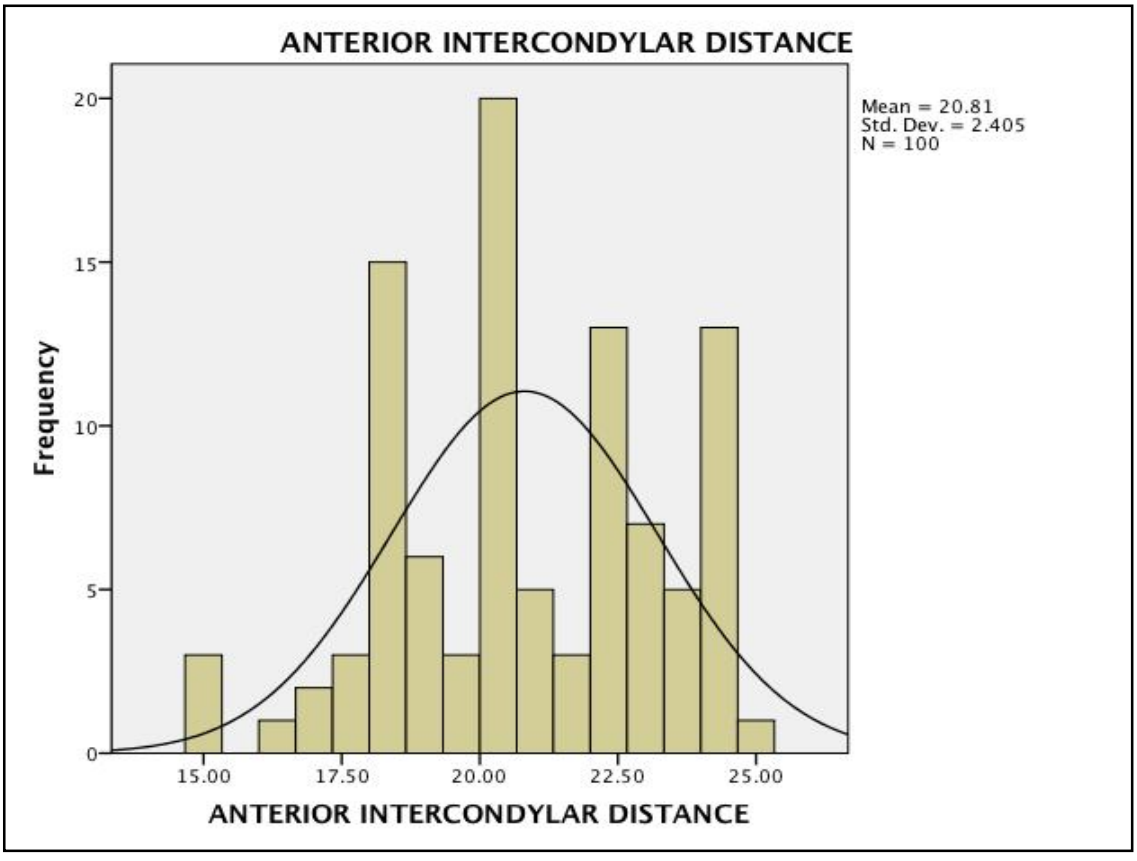
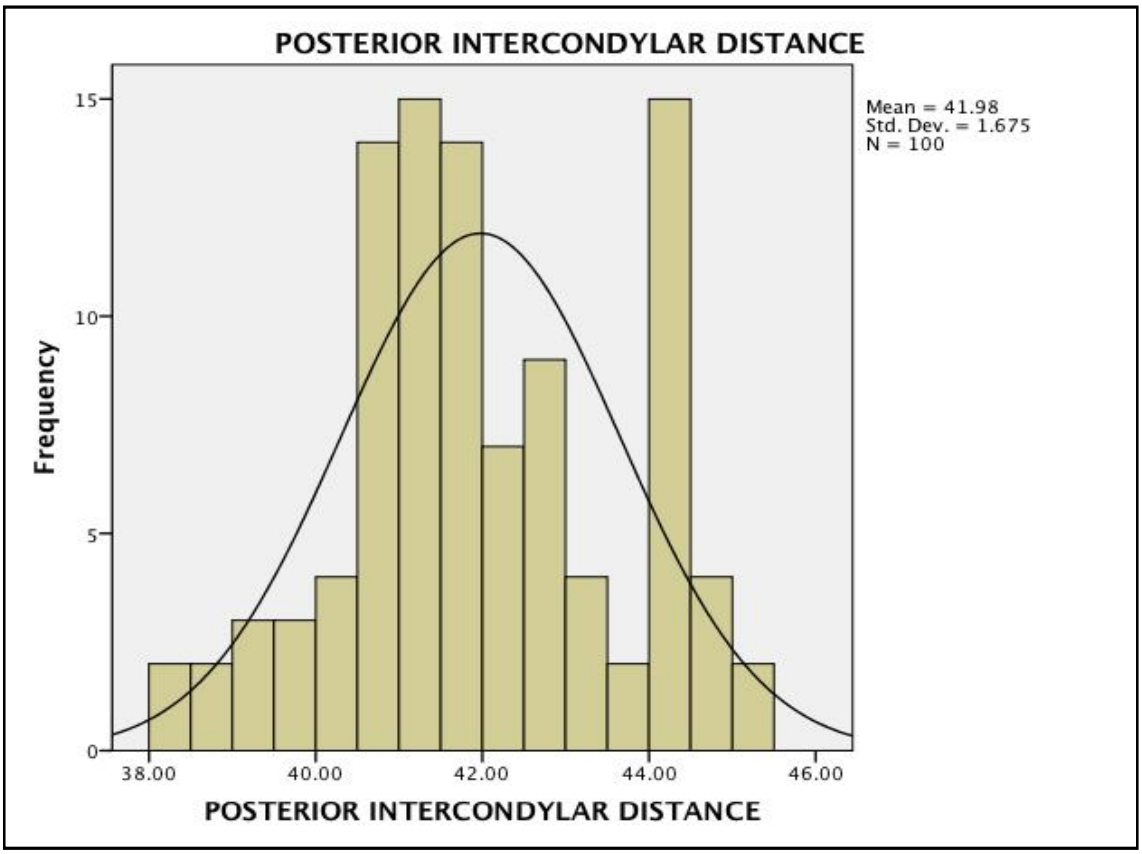


TABLE 19: POSTERIOR INTERCONDYLAR DISTANCE (PICD)

STATISTICAL DATA	PICD (in mm)
No. of skulls	100
Minimum	38.02
Maximum	45.43
Mean	41.97
S.D	1.67

The whole range of values is shown in the histogram with a bell shaped curve below.

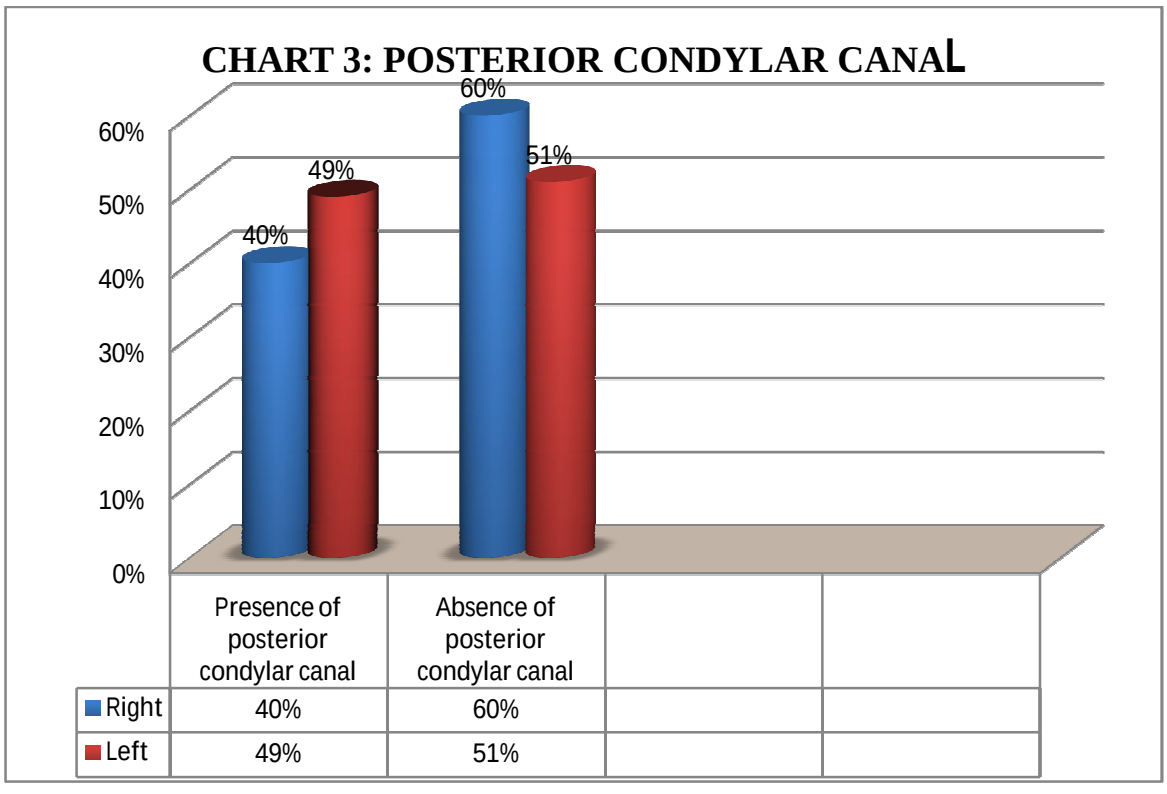


PRESENCE OF POSTERIOR CONDYLAR CANAL:

Of the 100 skulls examined, posterior condylar canal was found on the right side in 40 skulls and absent in 60 skulls. On the left side posterior condylar canal was found in 49 skulls and absent in 51 skulls and it was present bilaterally in 33skulls.

TABLE 20: SHOWING THE INCIDENCE OF PCC

SL.NO	POSTERIOR CONDYLAR CANAL		(N=100)	PERCENTAGE
1)	Present	Right	40	40%
		Left	49	49%
2)	Absent	Right	60	60%
		Left	51	51%



PRESENCE OF SEPTUM OF THE HYPOGLOSSAL CANAL:

Of the 100 skulls examined, HGC septum was found on the right side in 10 skulls and absent in 90 skulls and on the left side it was found in 20 skulls and absent in 80 skulls. Out of 100 skulls examined HGC septum was found in 24% and absent in 76 %.

TABLE 21: SHOWING THE INCIDENCE OF HGC SEPTUM

SL.NO	HYPOGLOSSAL CANAL SEPTUM		(N=100)	PERCENTAGE
1)	Present	Right	10	10%
		Left	20	20%
2)	Absent	Right	90	90%
		Left	80	80%

CHART 4: PRESENCE OF HYPOGLOSSAL SEPTUM

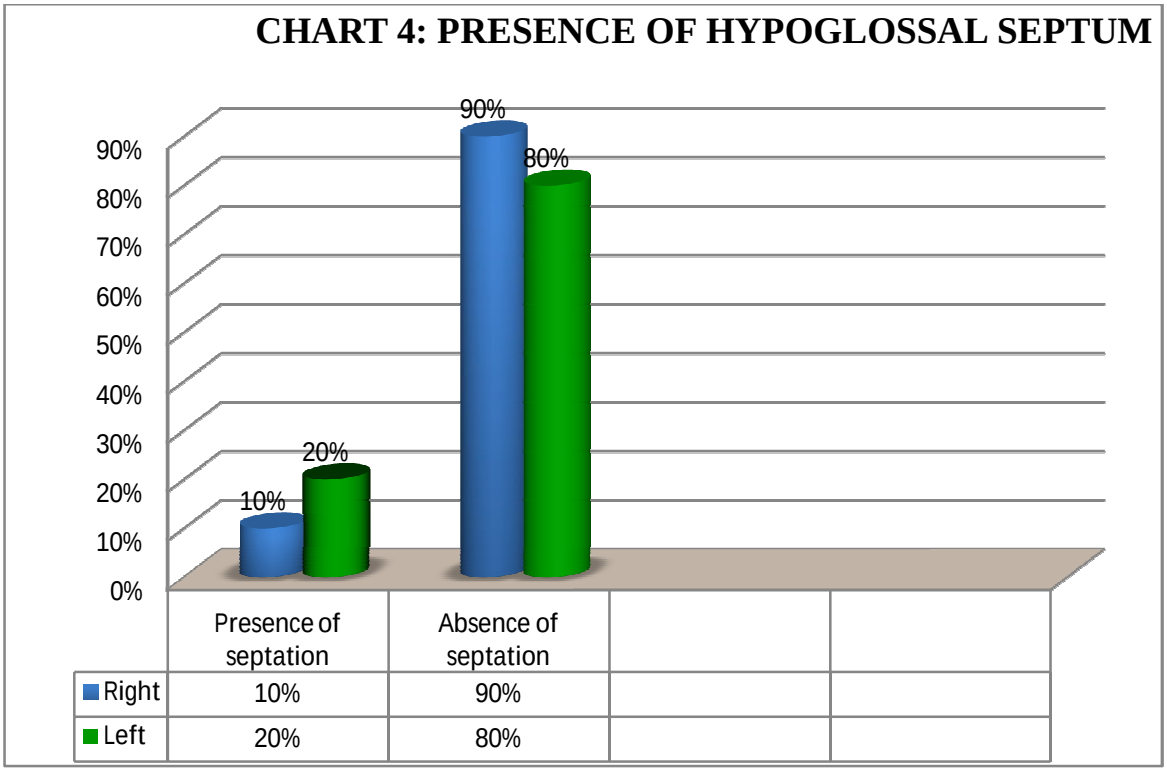


TABLE 22: DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HGC (RHGC) AND ANTERIOR MARGIN OF ROC

STATISTICAL DATA	DISTANCE BETWEEN RHGC AND ANTERIOR MARGIN OF ROC(in mm)
No. of skulls	100
Minimum	7.51
Maximum	15.25
Mean	11.02
S.D	1.29

The whole range of values is shown in the histogram with a bell shaped curve below.

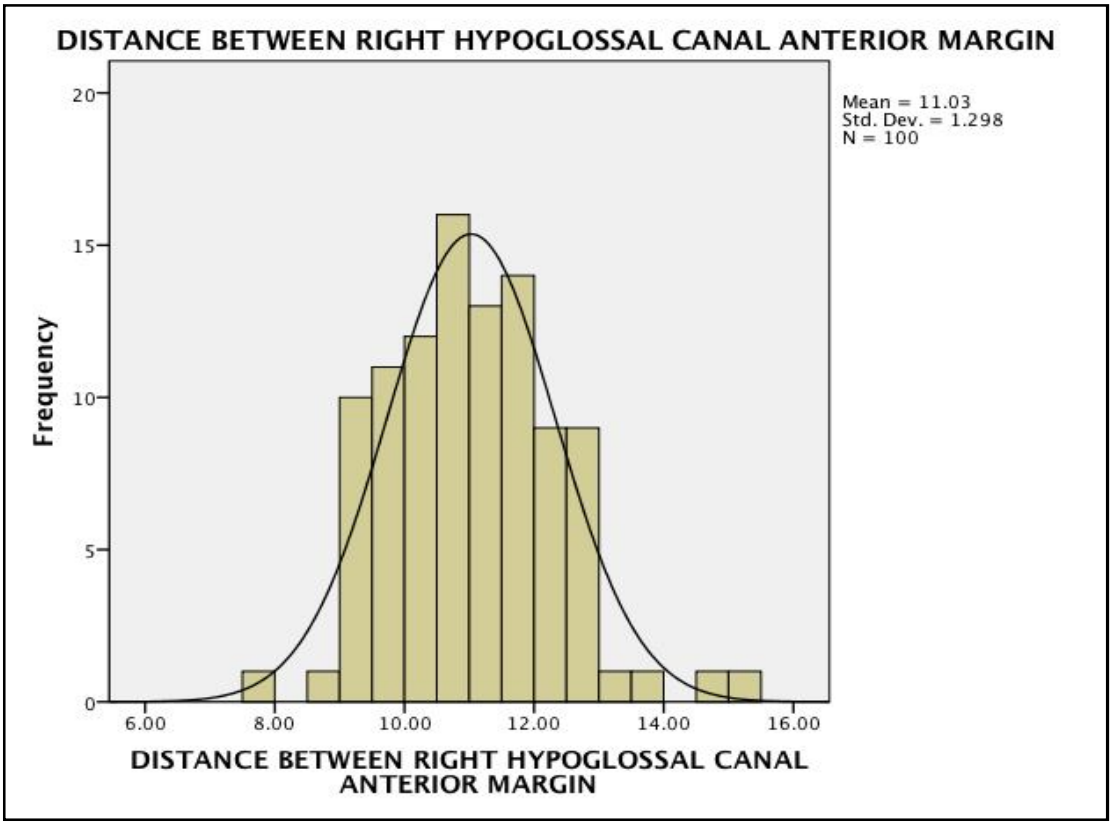


TABLE 23: DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HGC (RHGC) AND POSTERIOR MARGIN OF ROC.

STATISTICAL DATA	DISTANCE BETWEEN RHGC AND POSTERIOR MARGIN OF ROC (in mm)
No. of skulls	100
Minimum	9.8
Maximum	14.90
Mean	12.27
S.D	0.6

The whole range of values is shown in the histogram with a bell shaped curve below.

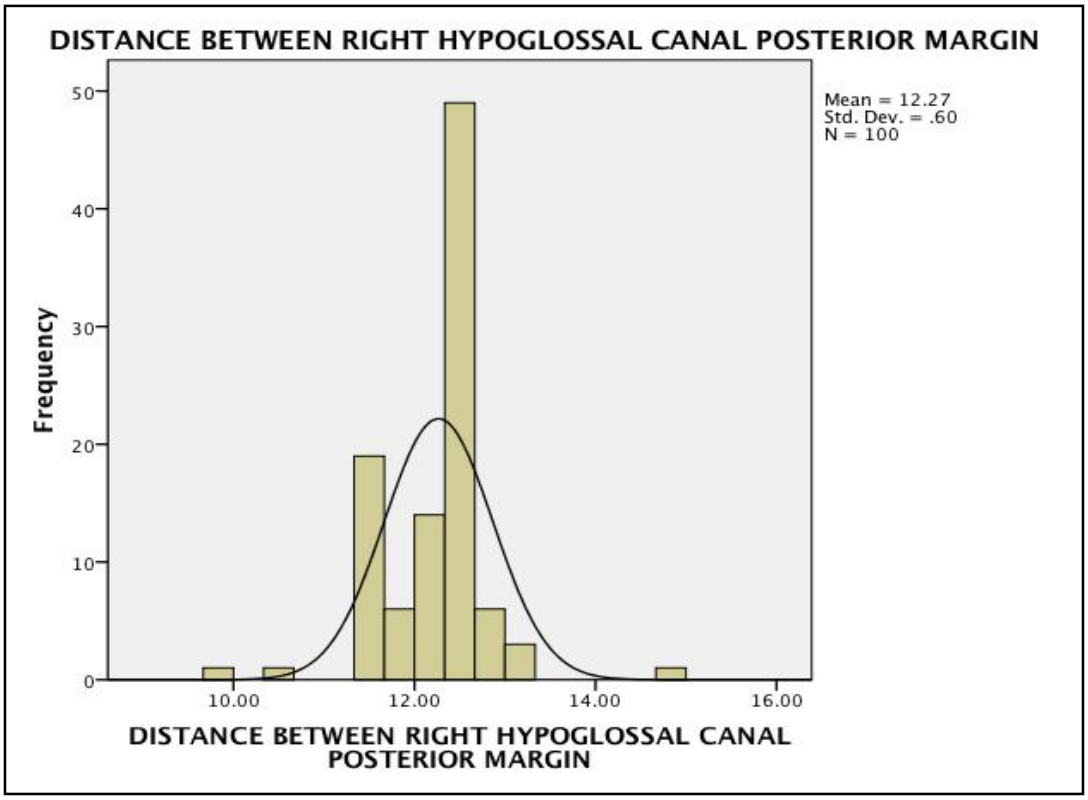


TABLE 24: DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HGC (LHGC) AND ANTERIOR MARGIN OF LOC.

STATISTICAL DATA	DISTANCE BETWEEN LHGC AND ANTERIOR MARGIN OF LOC(in mm)
No. of skulls	100
Minimum	6.81
Maximum	15.18
Mean	10.93
S.D	1.3

The whole range of values is shown in the histogram with a bell shaped curve below.

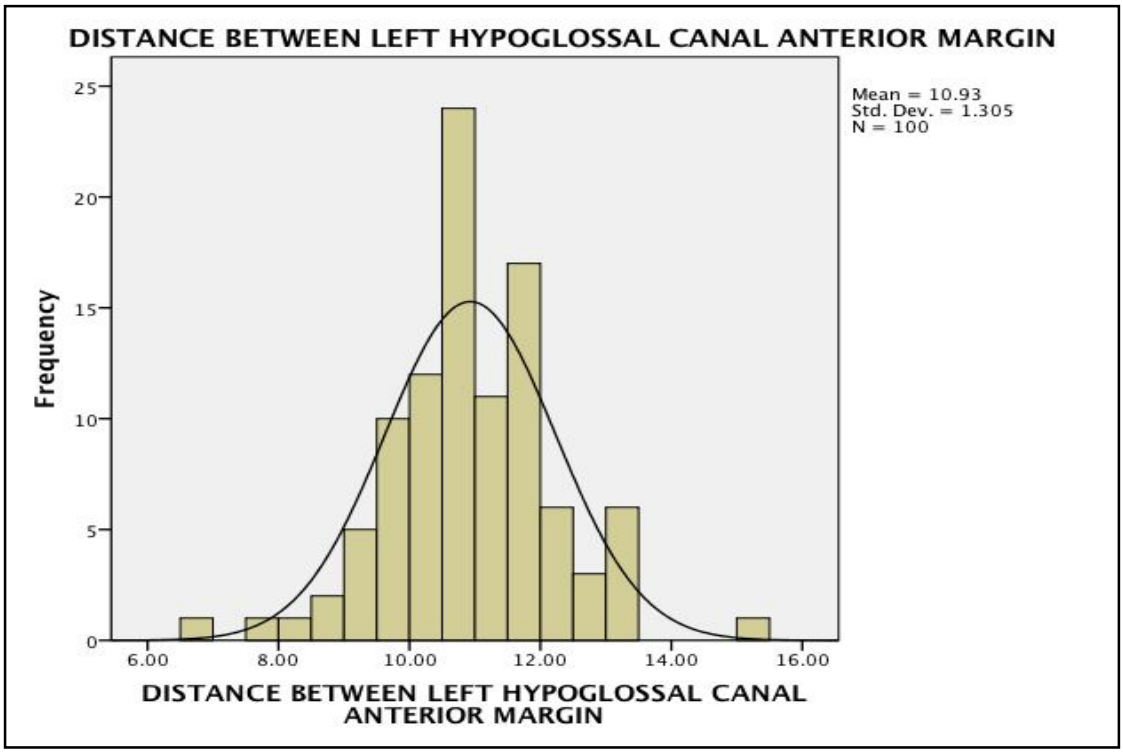


TABLE 25: DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HGC (LHGC) AND POSTERIOR MARGIN OF LOC.

STATISTICAL DATA	DISTANCE BETWEEN LHGC AND POSTERIOR MARGIN OF LOC (in mm)
No. of skulls	100
Minimum	9.6
Maximum	14.5
Mean	12.26
S.D	0.59

The whole range of values is shown in the histogram with a bell shaped curve below.

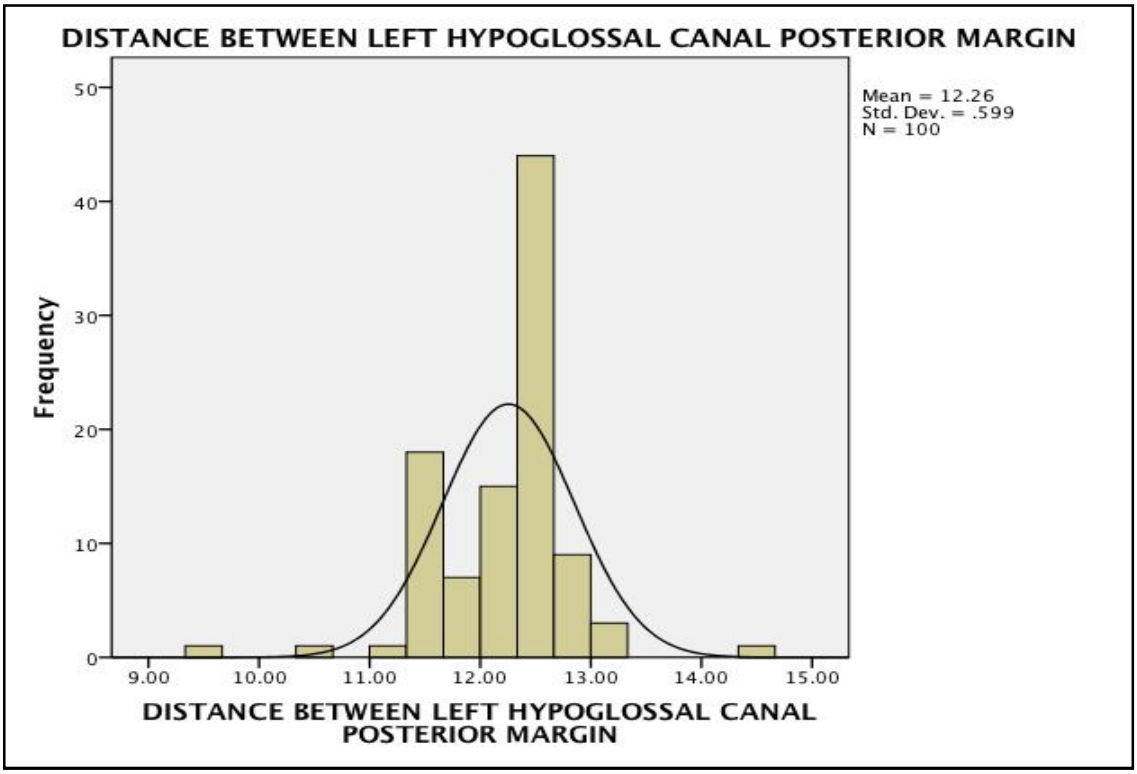


TABLE 26: COMPARISON OF THE DISTANCE BETWEEN HGC (RIGHT AND LEFT) AND ANTERIOR MARGIN AND DISTANCE BETWEEN HGC (RIGHT AND LEFT) AND POSTERIOR MARGIN OF ROC AND LOC OF DRY SKULL ALONG WITH t - VALUE AND p - VALUE.

STATISTICAL DATA	SIDE	N	Mean	SD	t- value	p-value
Distance between HGC and anterior margin	RIGHT	100	11.02	1.29794	0.537	0.592
	LEFT	100	10.93	1.30521		
Distance between HGC and posterior margin	RIGHT	100	12.26	0.59966	0.126	0.900
	LEFT	100	12.25	0.59853		

'p' value ≤ 0.05 is considered to be significant

No significant difference was observed between the right and left side of the specimen.

Discussion

DISCUSSION

The findings of the present study were correlated with the findings of other similar studies conducted in different parts of India and in other countries.

1) SHAPE OF THE FORAMEN MAGNUM

Muthukumar N et al [35](2005) reported that the FM was ovoid in 46%.

P. Chethan et al [41](2011) recorded that the FM was observed to be round in 22.6%, tetragonal in 18.9%, oval in 15.1%, egg shaped in 18.9%, pentagonal in 3.8% , irregular in 15.1%, and hexagonal in 5.6% of the cases.

Emel AVCL et al [9](2011) stated that the FM was oval in 58%.

Radhakrishnan S.K et al [46](2012) reported that the FM was oval in 39%, round in 28%, pentagonal in 14% and tetragonal in 19%of the cases.

Radhakrishnan P et al [45](2012) reported that the FM was oval in 35.2%, hexagonal in 24.8%, pentagonal in 12.4%,round in 7.6%,irregular in 11.6% ,trigonal in 1.6%, pentagonal in 12.4%and tetragonal in 6.8% in cranial CT.

K. Natsis et al [31](2013) found that the FM was two semicircles in 25.9%. It was pear shaped in 22.4 %, oval 14.7 %, egg shaped in 21 %, rhomboid in 14%,round in1.4 % and irregular in 0.7%.

Khalil Awadh Murshed et al [30] (2003)studied CT images of the FM and recorded that the FM was oval in 8.1%, egg shaped in 6.3%, round in 21.8%, pentagonal in 13.6%, irregular (type A) in 10.9%,hexagonal in17.2%, tetragonal in 12.7%, and irregular (type B) in 9.09%.

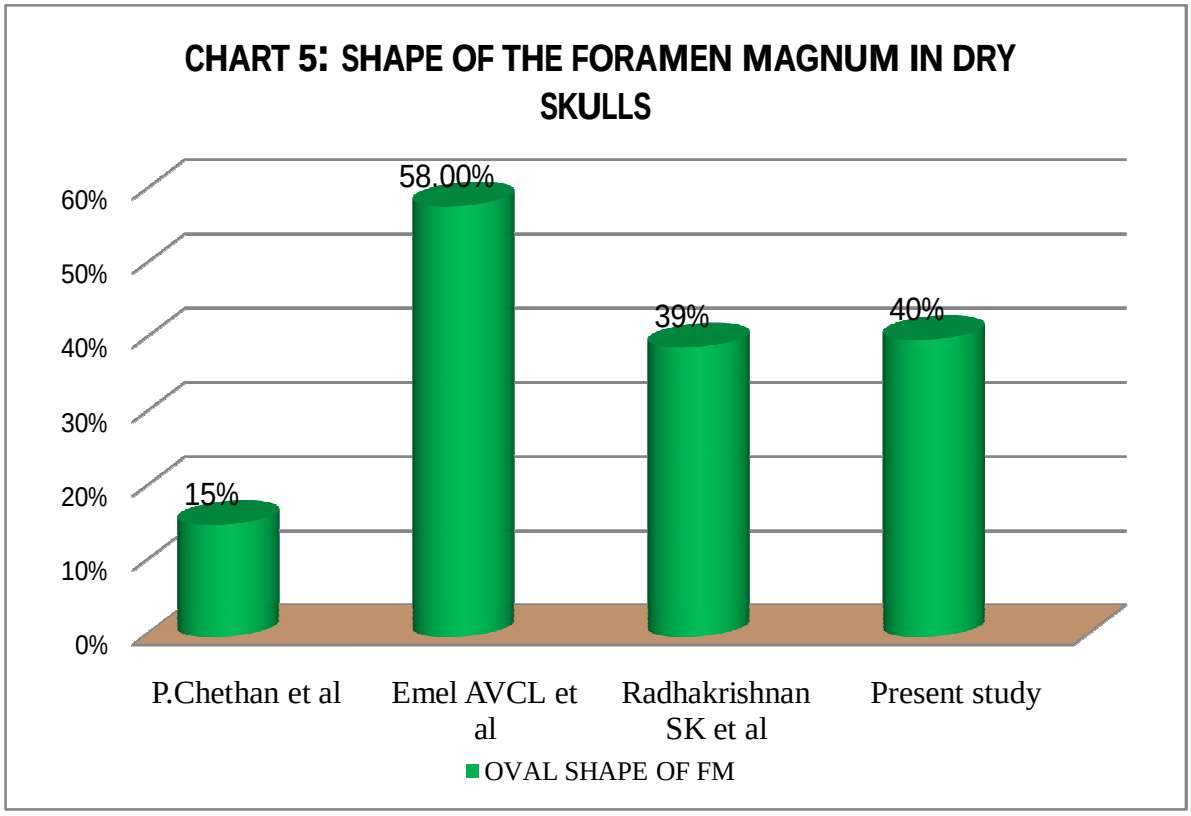
Gobbur et al [19] (2013) reported that the FM was round in 40% and oval in30% in CT images.

Comparison was done with various studies showing the shape of the FM and was tabulated.The most common shape of the FM was oval. The present study also showed that the FM was oval in 40% and egg shaped in 22%.

The variation in the shape of FM should be taken into consideration during neuroimaging techniques and surgical approaches. In the oval shaped FM, exposing the anterior portion might be difficult during surgeries.

TABLE 27: THE INCIDENCE OF FM OF DIFFERENT TYPES IN DRY SKULLS

Sl.NO	STUDY	YEAR OF STUDY	SHAPEOF THE FORAMEN MAGNUM					
			Oval	Egg shape	Round	Pentagonal	Hexagonal	Others
1)	P.Chethan et al	2011	15.1					84.9
2)	Emel AVCL et al	2011	58					42
3)	Radhakrishnan S.K et al	2012	39		28	14		19
4)	**Present study**	**2014**	**40**	**22**	**13**	**3**	**7**	**15**



2) MAXIMUM ANTEROPOSTERIOR DIAMETER OF THE FORAMEN MAGNUM (FM)

Georges Olivier et al [18](1975) reported that the mean AP diameter of the FMwas 35.7mm.

Manoel. C et al [33](2009) stated that the mean AP diameter of the FM of male and female were 35.7±0.29 mm and 35.1± 0.33 mm respectively.

Philipp Gruber et al [43](2009) recorded that the mean AP diameter ranged from 30.1mm.to 42.6mm with an average of 36.6mm.

Fatma Hayat Eridil et al [13](2010) stated that the mean AP diameter of the FM was 35±5.8mm in CT scans.

Emel AVCL et al [9](2011) found that the mean AP diameter of the FM was 34.5mm.

F.Burdan et al [11](2012) recorded the mean AP diameter of the FM in male and female were 37.06mm and 35.57 mm respectively in CT scans.

Gautam Kanodia et al [17](2012) concluded that the mean AP diameter of the FM was 34.1±0.29mm in dry skull group and 33.1±0.35mm in CT scan.

Osunwoke E.A et al [38](2012) reported that the mean AP diameter of the FM was 36.11±0.24mm.

Radhakrishnan P et al [45](2012) concluded that the AP diameter of FM varied from 25.8mm to 45.9mm with the average of 35.76±3.4mm in cranial CT scans.

Fathy Ahmed Fetouh et al [12](2013) recorded that the AP diameter of FM varied from 31mm to 40.2mm with the average of 34.94mm.

K. Natasis et al [31] (2013) recorded that the mean AP diameter of the FM was 35.53±3.06mm.

Yogesh Yadav et al [59](2014) reported that the mean AP diameter of the FM of male and female were 35.22± 2.17mm and 33.1±2.04mm respectively.

In the **Present study,** the AP diameter of FM ranged from 24.64mm to 39.89mm with the average of 35.12±2.65mm. The mean AP diameter of the FM was compared with that found in various other studies and tabulated.

Longer anteroposterior dimension of the FM permits greater surgical exposure for occipital condyle resection.

TABLE 28: COMPARISON OF AP DIAMETER OF THE FM IN DRY SKULLS

SL No	STUDY	YEAR OF STUDY	AP DIAMETER OFFM IN DRY SKULLS (in mm)
1)	Georges Olivier et al	1975	35.70
2)	Philipp Gruber et al	2009	36.60
3)	Emel AVCL et al	2011	34.50
4)	Osunwoke E.A et al	2012	36.11
5)	K.Natasis et al	2013	35.53
6)	**Present Study**	**2014**	**35.12**

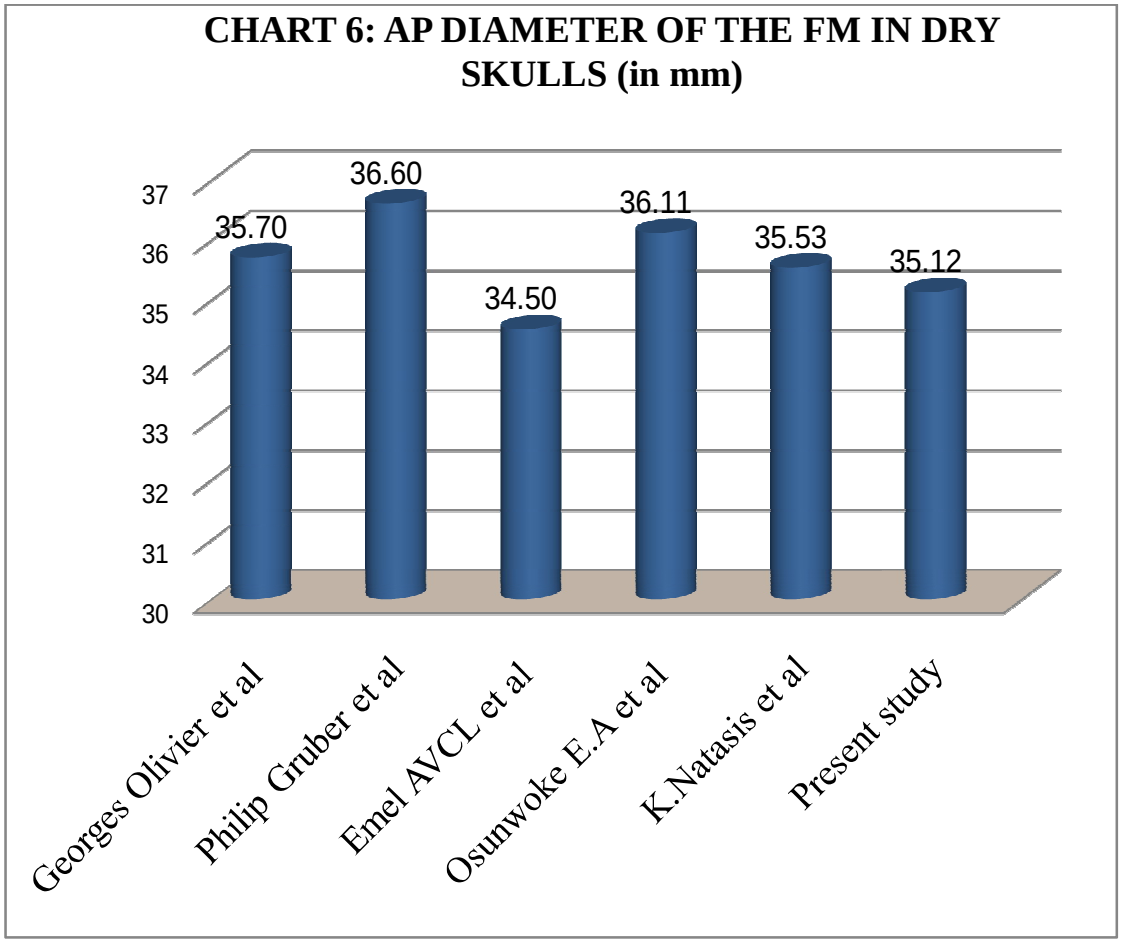
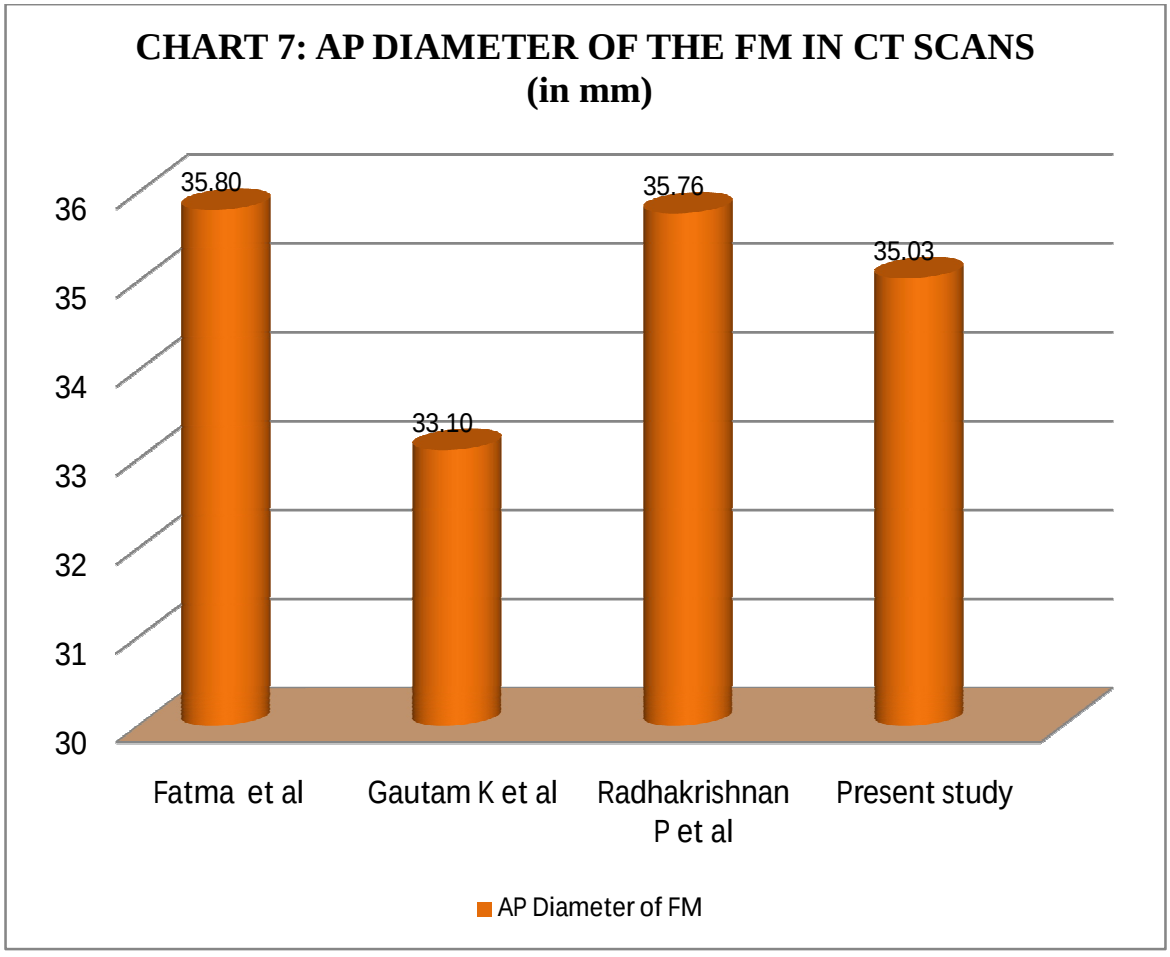


TABLE 29: COMPARISON OF AP DIAMETER OF THE FM IN CT SCAN IMAGES

Sl. No	STUDY	YEAR OF STUDY	AP DIAMETER OF FM IN CT SCANS (in mm)
1)	Fatma et al	2010	35.58
2)	Gautam K et al	2012	33.10
3)	Radhakrishnan P et al	2012	35.76
4)	**Present study**	**2014**	**35.03**



The mean AP diameter of FM in dry skulls and CT scan of various studies were in between 34.5mm and 36.6mm. In the present study, it was found that the mean AP diameter of FM in adult dry skulls and cranial CT were 35.12mm and 35.03mm respectively.

The size of FM is the critical parameter in craniovertebral junction pathologies for the manifestations of clinical signs and symptoms. Achondroplasia due to diminished growth of skull base may result in stenosis of Craniovertebral canal.[5] It requires surgical decompression with resection of posterior aspect of FM.

3) MAXIMUM TRANSVERSE DIAMETER OF THE FORAMEN MAGNUM (FM)

Georges Olivier [18](1975) stated that the mean transverse diameter of the FM was 30.34 mm.

Fatma Hayat Eridil et al [13](2010) studied CT scans and reported that the mean transverse diameter of the FM was 29.84mm.

Emel AVCL et al [9](2011) stated that the mean transverse diameter of FM was 29mm.

Gautam Kanodia et al [17](2012) reported that the mean transverse diameter of the FM was 27.5±0.25mm in dry skull group and 27.6±0.31mm in cranial CT scan.

Osunwoke E.A et al [38](2012) reported that the mean transverse diameter of the FM was29.65±0.24mm.

Radhakrishnan P et al [45](2012) reported that the mean transverse diameter of FM ranged from 22mm to 39.1mm with the average of 29.79±2.85mm in cranial CT scans.

K. Natasis et al [31](2013) reported the mean transverse diameter of the FMwas 30.31±2.79mm.

In the **Present study,** the transverse diameter of FM varied from 24.01mm to 35.98mm with the average of 29.03±2.15mm. The mean transverse diameter of the FM found in various studies were compared with this value and tabulated.

Understanding of the bony landmarks of FM is important in transcondylar approach.

TABLE30:COMPARISON OF TRANSVERSE DIAMETER OF THE FM IN DRY SKULLS

SL No	STUDY	YEAR OF STUDY	TRANSVERSE DIAMETER OF FM IN DRY SKULLS (in mm)
1)	Georges Oliver et al	1975	30.34
2)	Emel AVCL et al	2011	29.00
3)	Osunwoke E.A et al	2012	29.65
4)	K.Natasis et al	2013	30.31
5)	**Present Study**	**2014**	**29.03**

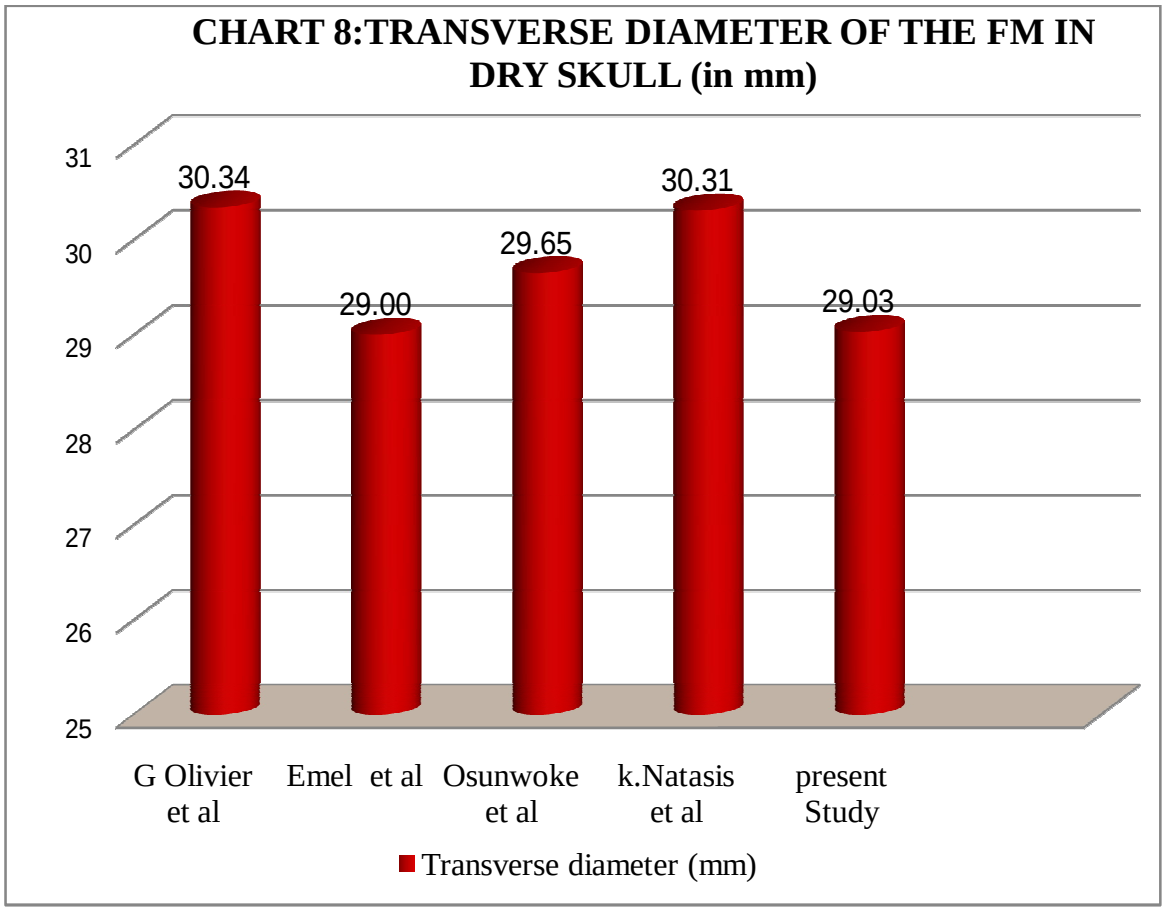
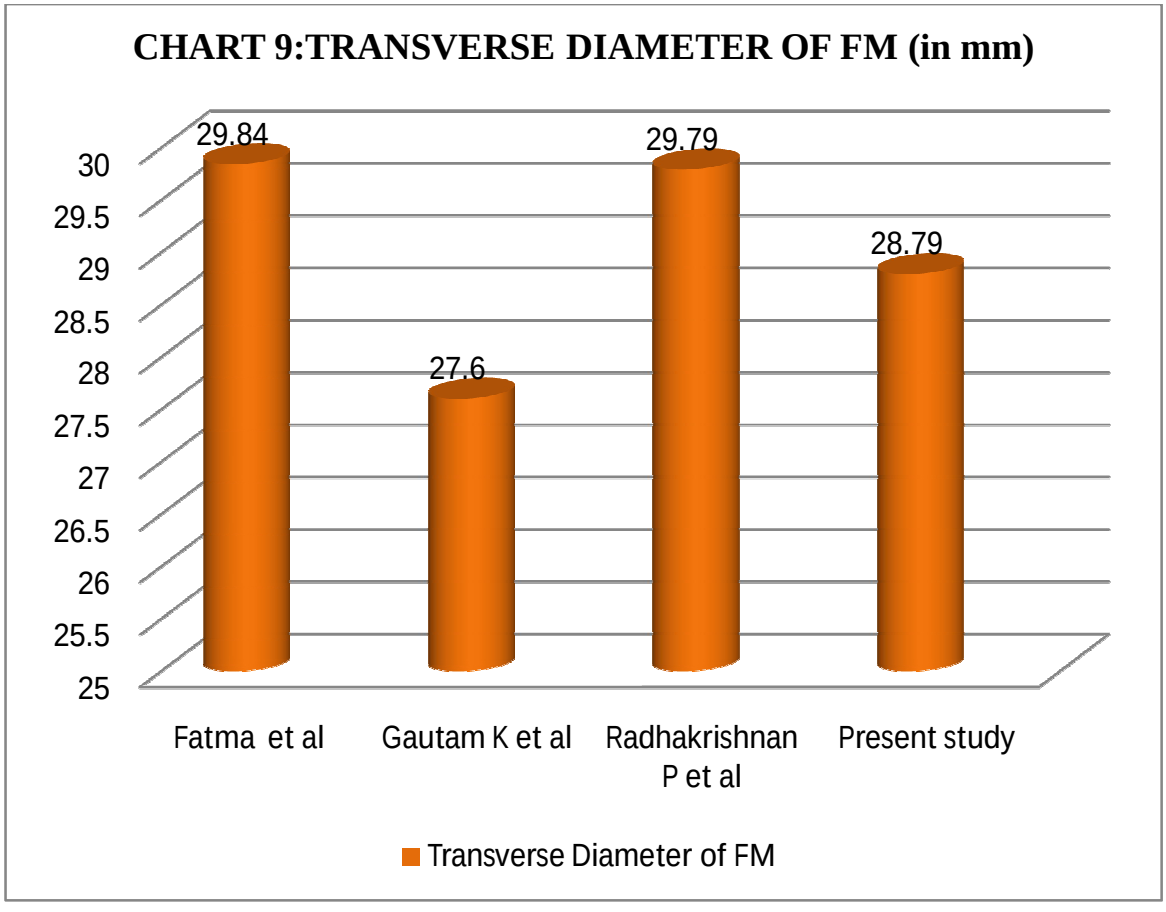


TABLE 31: COMPARISON OF TRANSVERSE DIAMETER OF THE FM IN CT SCAN IMAGES

SL No	STUDY	YEAR OF STUDY	TRANSVERE DIAMETER OF FM IN CT SCAN(in mm)
1)	Fatma et al	2010	29.84
2)	Gautam K et al	2012	27.60
3)	Radhakrishnan Pet al	2012	29.79
4)	**Present study**	**2014**	**28.79**



The mean transverse diameter of FM in dry skulls and CT scans of various studies gave values in between 34.5mm and36.6mm. In the present study, the mean transverse diameter of FM in adult human dry skulls and cranial CT were measured as 29mm and 28.79mm respectively. Minor controversies were seen in some studies.

The diminished size of FM is seen in craniometaphyseal dysplasia and Marchesani's syndrome which cause stenos is of Craniovertebral junction.

4) PROTRUSION OF OCCIPITAL CONDYLE INTO THE FORAMEN MAGNUM.

Muthukumar N et al [35](2005) reported that the OCs protrude into the FM in 20% of adult dry skulls.

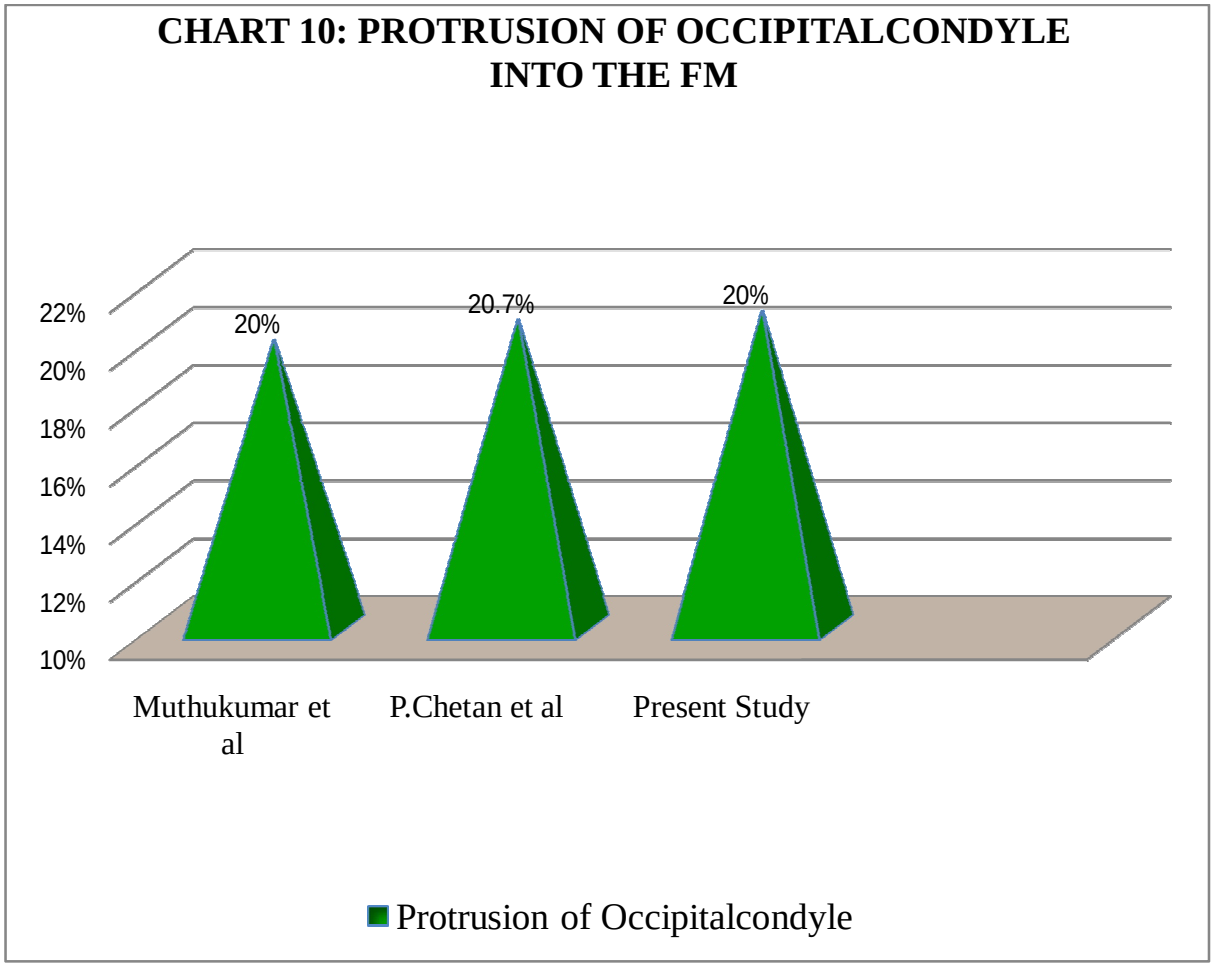
P. Chethan et al [41](2011)and **Emel AVCL et al [9] (2011)**found that the OCs protruded into the FM in 20.7% and57% of skulls respectively.

In the **Present study** it was found that the occipital condyles protruded into the FM in 20% of adult dry skulls.

In other studies, protrusion of OC into the FM was mostly seen in oval or egg shaped FM. In case of protrusion of OC, more extensive removal of OC may be indicated during surgeries involving skull base, which may cause greater craniovertebral instability.

TABLE 32: COMPARISON OF INCIDENCE OF PROTRUSION OF OC INTO THE FORAMMEN MAGNUM

SL No	STUDY	YEAR OF STUDY	PROTRUSION OF OC INTO THE FM
1)	Muthukumar et al	2012	20%
2)	P.Chetan et al	2011	20.7%
3)	**Present Study**	**2014**	**20%**



5) LENGTH OF THE RIGHT OCCIPITAL CONDYLE

Georges Olivier [18](1975) reported that the mean length of the ROC was 23.75mm.

Muthukumar N et al [35](2005) and Sait Naderi et al [49] (2005) reported that the length of the ROC was 23.6mm.

Emel AVCL et al [9](2011) reported that the mean maximum length of ROC varied from 18.2mm to 28.7mm with an average of 23.7±2.6 mm.

Mehmet Asim Ozer et al [34] (2011) recorded that the mean length ofROC was 23.9±3.4mm.

Tien V et al [56] (2011) stated that the mean length of ROC was 22.2±2.1mm in cranial CT scans.

Fathy Ahmed Fetouh et al [12] (2013) recorded that the mean maximum length of ROC ranged from 18mm to 31mm with an average of 23.5mm.

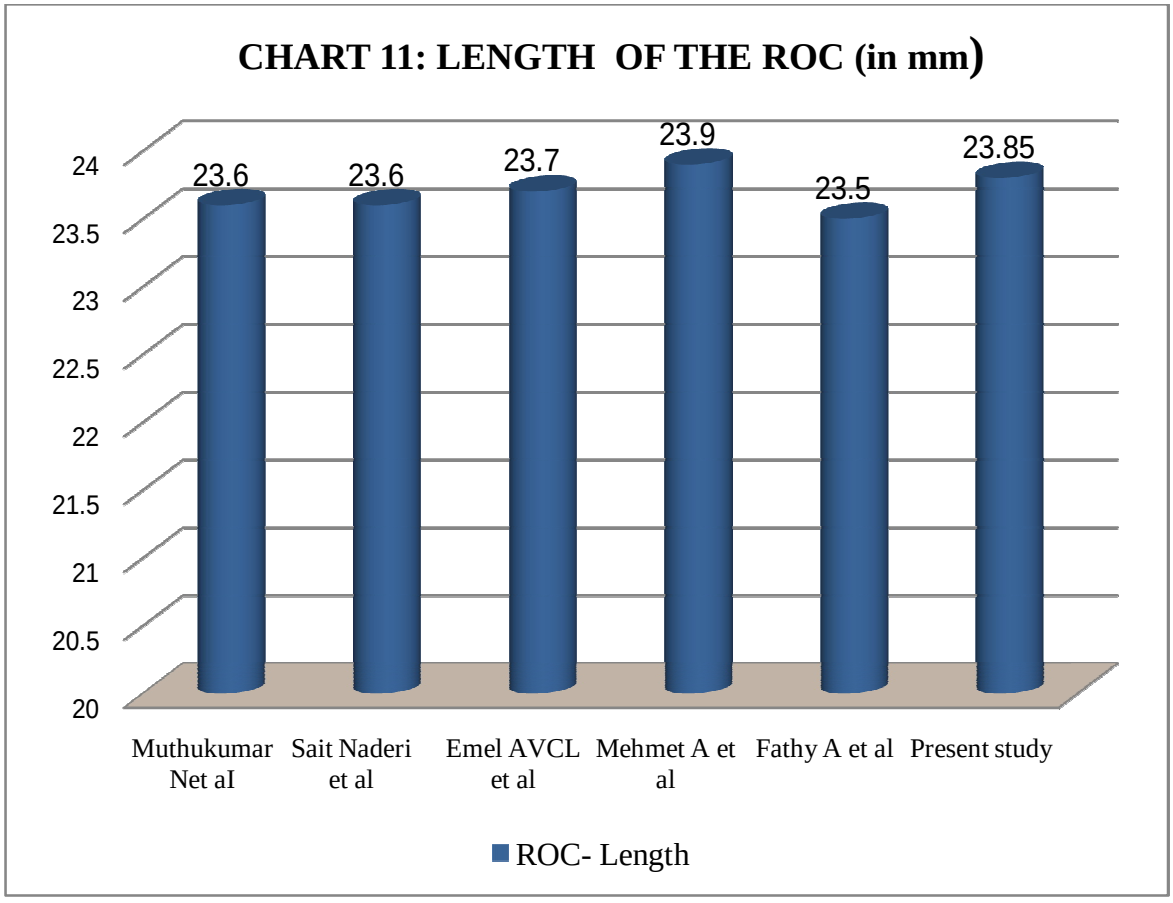
Bello S.S et al [4](2013) reported in cranial CT that the mean length of ROC was 23.5±2.7mm.

In the **Present study** the mean maximum length of ROC ranged from 18.16mm to 32.68mm with an average of 23.85±2.12mm.

The mean maximum lengths of ROC were compared and results shown in the table where the values were in between 23.5mm and 23.85mm.

TABLE 33: COMPARISON OF MAXIMUM LENGTH OF ROC

SL.NO	STUDY	YEAR OF STUDY	ROC-LENGTH (in mm)
1)	Muthukumar Net aI	2005	23.60
2)	Sait Naderi et al	2005	23.60
3)	Emel AVCL et al	2011	23.70
4)	Mehmet Asim Ozer et al	2011	23.90.
5)	Fathy Ahmed Fetouh et al	2013	23.50
6)	**Present study**	**2014**	**23.85**



6) MAXIMUM WIDTH OF THE RIGHT OCCIPITAL CONDYLE

Muthukumar N et al [35](2005) found that the mean ROC width was 14.72mm.

Sait Naderi et al [49](2005) reported that the ROC width was 10.6mm.

Emel AVCL et al [9](2011) recorded that the maximum width of ROC varied from 9 mm to 14.5 mm with an average of 12.2±1.2mm .

Pereira G.A et al [42](2012) reported that the ROC mean width was 13.4±1.4mm.

Bello S.S et al [4](2013) stated that the mean width of ROC in cranial CT was 12.8±1.7mm.

Fathy Ahmed Fetouh et al [12](2013) recorded that the mean maximum width of ROC ranged from 9.5mm to 18mm with an average of 13.58mm.

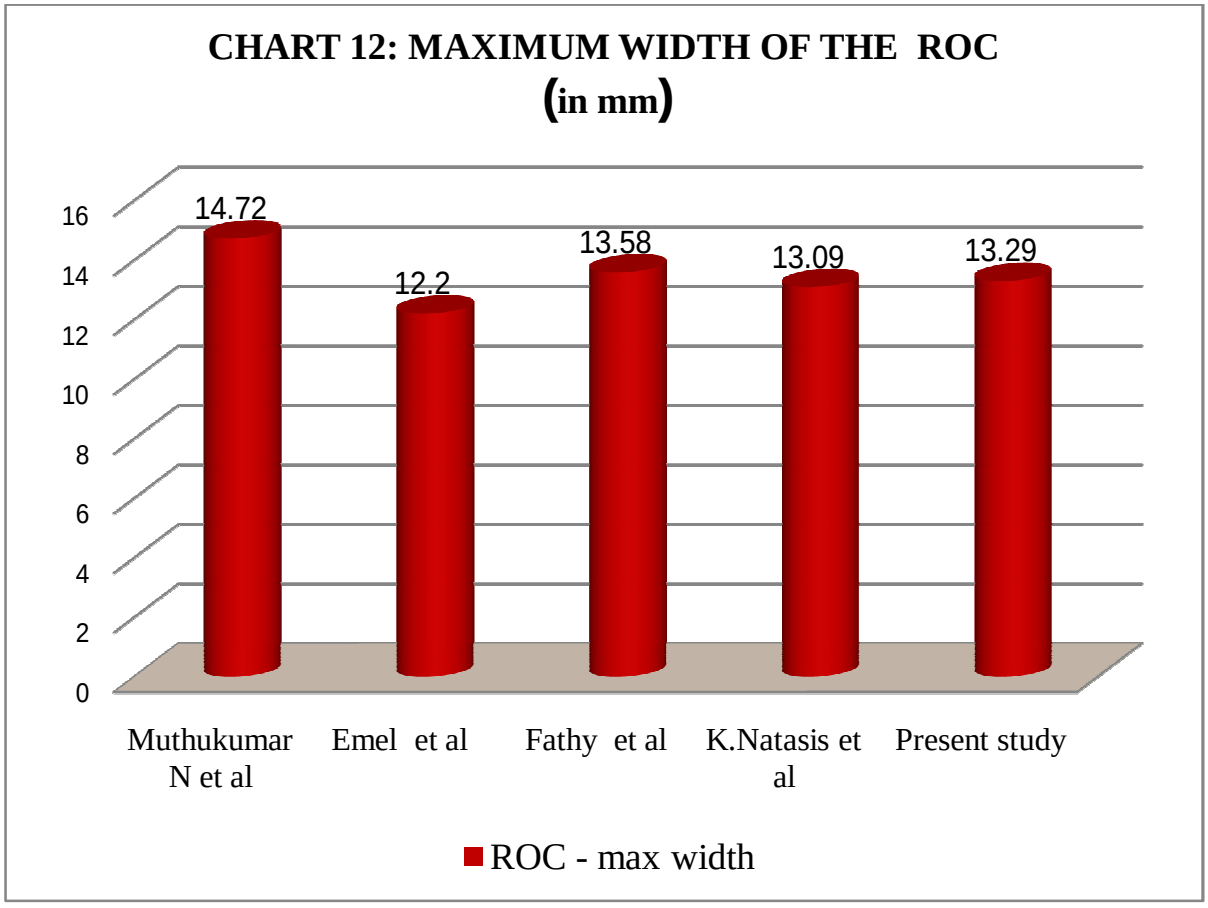
K. Natasis et al [31](2013) found that the ROC maximum width was 13.09±1.99mm.

In the **Present study** the maximum width of ROC was in the range of 9.76mm to 16.19mm with an average of 13.29 ±1.36mm.

The maximum length of ROC was compared and results shown in the table where the values were in between 12.2mm and 14.72mm.

TABLE 34: COMPARISON OF MAXIMUM WIDTH OF ROC

SL.NO	STUDY	YEAR OF STUDY	ROC -MAXIMUM WIDTH (in mm)
1)	Muthukumar N et al	2005	14.72
2)	Emel AVCL et al	2011	12.20
3)	Fathy Ahmed et al	2013	13.58
4)	K.Natasis et al	2013	13.09
5)	**Present study**	**2014**	**13.29**



7) MINIMUM WIDTH OF THE RIGHT OCCIPITAL CONDYLE

K. Natasis et al [31](2013) found that the minimum width of ROC was 5.71±1.61mm.

In the**Present study** the minimum width of ROC was in the range of 3.25mm to 10.62mm with an average of 6.86mm.

8) LENGTH OF THE LEFT OCCIPITAL CONDYLE

Sait Naderi et al [49](2005) reported that the length of the LOC was 23.2mm.

Emine et al [10](2006) reported that the LOC length varied from 18.2mm to 31.1mm with an average of 24.6±2.5mm

Emel AVCL et al [9](2011) reported that the maximum length of LOC was in the range of 18.8 mm to 30.9mm with an average of 24.7±2.7mm.

Mehmet Asim Ozer et al [34](2011) recorded that the length of LOC was 23.92±3.3mm.

Tien V et al [56](2011) stated that the mean length of LOC was 22.5±2.2mm in cranial CT scans.

Pereira G.A et al [42](2012) reported that the LOC mean length was 23.3±2.6mm.

Bello S.S et al [4](2013) reported that the mean length of LOC was 23.7±2.8mm in CT scans.

Fathy Ahmed Fetouh et al [12](2013)recorded that the mean length of LOC varied from 18.3mm to 29.4mm with an average of 23.75mm.

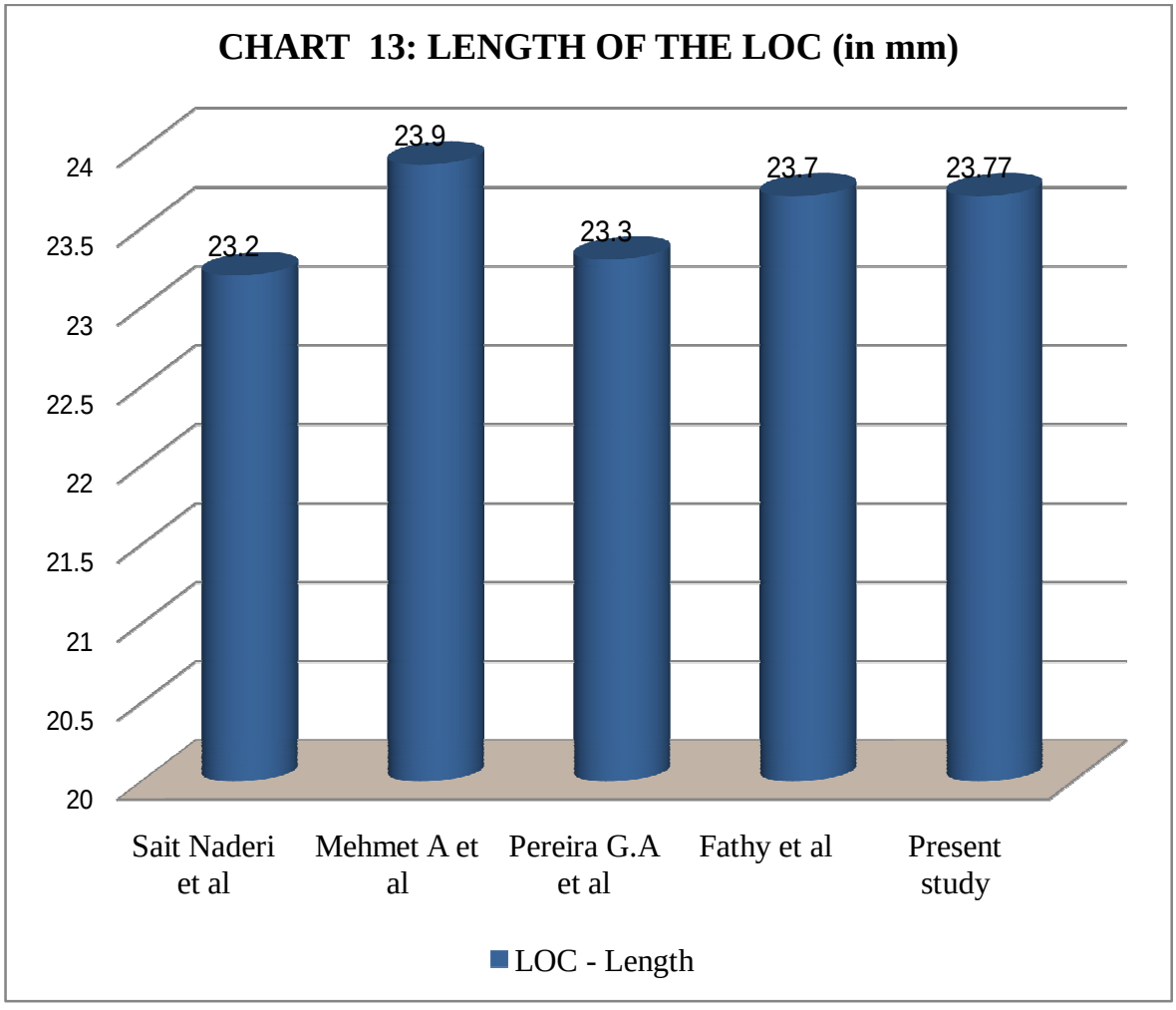
K. Natasis et al [31](2013) found that the LOC length was 25.60±2.70mm.

In the **Present study** the maximum length of LOC was in the range of 17.25 mm to 32.02mm with an average of 23.77±2.29mm.

The maximum length of OC on right and left side was compared and results shown in the table, where the values were in between 23.50mm and 23.85mm.

TABLE 35: COMPARISON OF MAXIMUM LENGTH OF LOC

SL.NO	STUDY	YEAR OF STUDY	LOC LENGTH (in mm)
1)	Sait Naderi et al	2005	23.20
2)	Mehmet Asim Ozer et al	2011	23.90
3)	Pereira G.A et al	2012	23.3
4)	Fathy Ahmed Fetouh et al	2013	23.70
5)	**Present study**	**2014**	**23.77**



9) MAXIMUM WIDTH OF THE LEFT OCCIPITAL CONDYLE

Emine et al [10](2006) reported that the width of the LOC was from 10.1mm to 17.2mm with an average of 13±1.5mm.

Emel AVCL et al [9](2011) reported that the maximum width of LOC on left side varied from 9.3 mm to 15.3 mm with an average of 12.4±1.5mm.

Mehmet Asim Ozer et al [34](2011) recorded that the width of LOC was 10.7±2.3mm.

Tien V et al [56](2011) stated that the mean width of LOC was 11.2±1.5mm in cranial CT scans.

Bello S.S et al [4](2013) reported that the mean breadth of LOC was 12.7±1.4mm in CT.

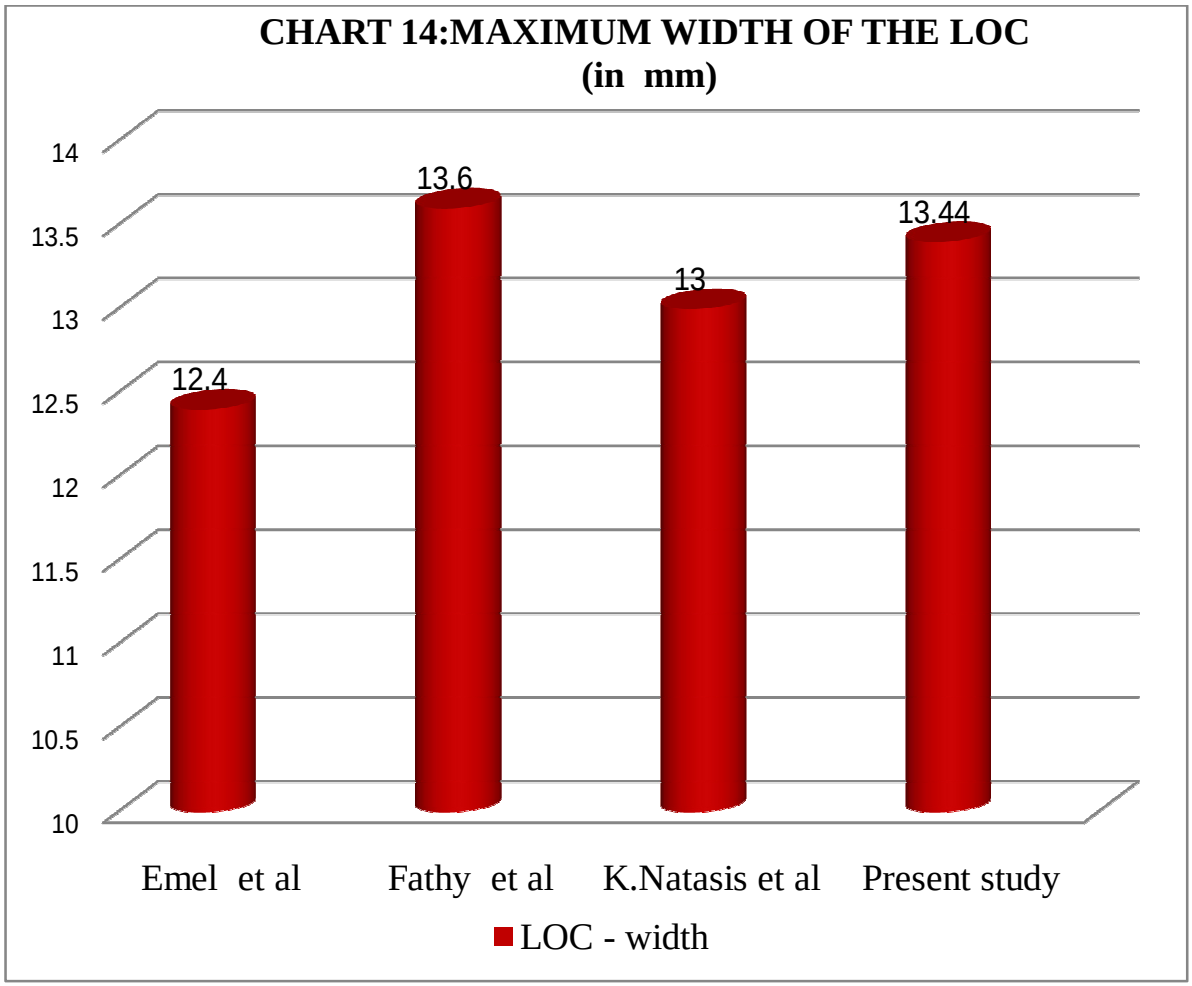
Fathy Ahmed Fetouh et al [12](2013) recorded that the maximum width of LOC ranged from 10.2mm to 16.8mm with an average of 13.62mm.

K.Natasis et al [31](2013) found that the maximum width of LOC was 13.01±1.98mm.

In the **Present study** the maximum width of the LOC ranged from 9.85 mm to 16.78 mm with an average of 13.44±1.4mm.

TABLE 36: COMPARISON OF MAXIMUM WIDTH OF LOC

SL.NO	STUDY	YEAR OF STUDY	LOC - MAXIMUM WIDTH (in mm)
1)	Emel AVCL et al	2011	12.40
2)	Fathy Ahmed et al	2013	13.60
3)	K.Natasis et al	2013	13.00
4)	**Present study**	**2014**	**13.44**



10) MINIMUM WIDTH OF THE LEFT OCCIPITAL CONDYLE

K. Natasis et al [31](2013) found that the minimum width of LOC was 6.25±1.76mm.

In the **Present study** the minimum width of LOC ranged from 4.7 mm to 10.32 mm with an average of 7.04±1.26mm.

TABLE 37: COMPARISON OF OC DIMENSION OF THE PRESENT STUDY WITH OTHER RADIOLOGICAL STUDIES.

SL.NO	STUDY	YEAR OF STUDY	ROC		LOC	
			LENGTH(in mm)	WIDTH (in mm)	LENGTH (in mm)	WIDTH (in mm)
1)	Tein et al	2011	22.20	11.20	22.50	11.20
2)	Bello et al	2013	23.50	12.80	23.70	12.70
3)	**Present study**	**2014**	**23.11**	**12.92**	**23.20**	**12.88**

In the **Present study** it was found that the mean length of ROC and LOC were 23.85mm and 23.77mm respectively in dry skulls. The mean length of ROC and LOC were 23.11mm and 23.20mm respectively in cranial CT.

The mean width of ROC and LOC were 13.29mm and 13.44mm respectively in dry skulls. The mean width of ROC and LOC were 12.92mmand 12.88mm respectively in cranial CTs. The measurements of OC in dry skulls were greater than those in cranial CT scans.

The OC forms the lateral boundary of the FM. The morphology and metric measurements of OC may affect the skull base surgery. The transcondylar approach is the optimal approach to resect lesions present ventral to FM.[37]Many studies agreed that the craniovertebral stability was not affected by one third removal of OC, however, in short OCs the same amount of condylectomy may cause Craniovertebral instability. Long OC may require more extensive resection for better surgical exposure.

11) BICONDYLAR DISTANCE (BCD)

Daniel J et al [7](2001) reported that the BCD of black male and female were 49.6mm and 47.3mm respectively and white male and female were 51.9mm and 49.8mm respectively

Gagandeep Singh et al [15](2012) reported that the BCD of male and female were 46.73mm and 44.29mm respectively.

In the **Present study,** the maximum bicondylar distance of the FM ranged from 32.71mmto 53.75mm with an average of 47.23±3.10 mm.

The BCD may show differences between skulls of female and male, which is greater in male.

12) ANTERIOR INTERCONDYLAR DISTANCE (AICD)

Daniel J et al [7](2001) reported that the AICD of black male and female were 20.1mm and 18.6mm respectively and white male and female were 20.9mm and 19.2mm respectively

Sait Naderi et al [49](2005) stated that the AICD was 21.0mm.

Emine et al [10](2006) reported that the AICD varied from 15mm to 32mm with an average of 22.6±3.9mm.

Mehmet AsimOzer et al [34](2011) recorded that the mean AICD was 20.9±3.6mm.

di Vasudha V. Saralaya et al [8](2012) reported that the mean AICD was 18.7mm.

Gagandeep Singh et al[15](2012) reported that the minimum intercondylar distance of the FM of male and female were 14.88mm and 14.33mm respectively.

Fathy Ahmed Fetouh et al [12](2013) recorded that the AICD varied from 11.5mm to 25.5mm with an average of 20.64mm.

K. Natasis et al [31](2013) found that the mean AICD was 19.30±3.25mm.

Pooja Gangrade et al [44](2013) recorded that the mean AICD of male and female were 18.32mm and 15.44mm respectively.

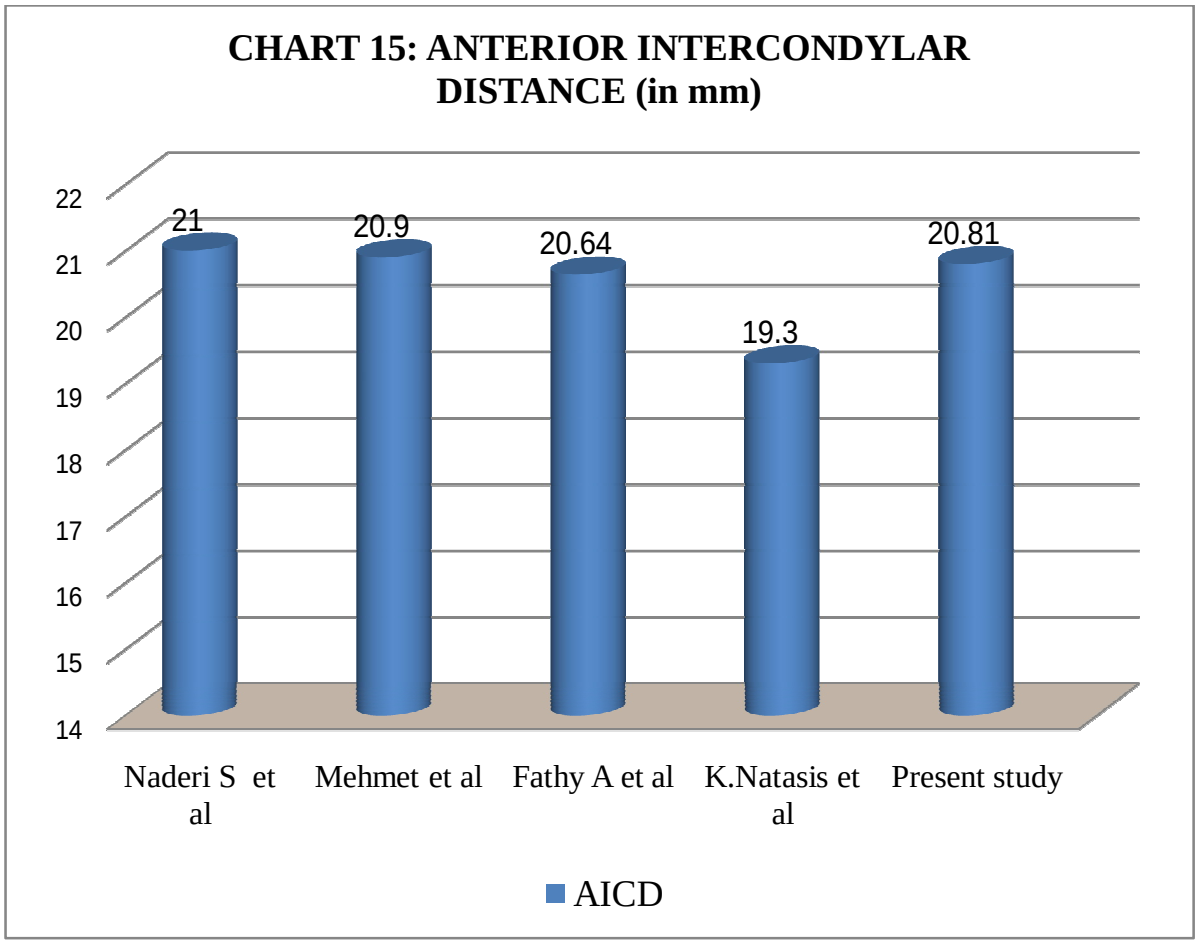
Parvindokht Bayat et al [39](2014) found that the AICD ranged from 2mm to 42mm with an average of 15.39±7.99mm.

In the **present study** the AICD was in the range of 14.87mm to 25.16mm with an average of 20.81±2.40mm.

The values of present study coincided with various other studies.

TABLE 38: COMPARISON OF ANTERIOR INTERCONDYLAR DISTANCE.

Sl.No	STUDY	YEAR OF STUDY	AICD (in mm)
1)	Sait Naderi et al	2005	21.00
2)	Mehmet AsimOzer etal	2011	20.90
3)	Fathy Ahmed Fetouh et al	2013	20.64
4)	K.Natasis et al	2013	19.30
5)	**Present study**	**2014**	**20.81**



13) POSTERIOR INTERCONDYLAR DISTANCE (PICD)

di Vasudha V. Saralaya et al [8](2012) reported that the mean PICD was 38.7mm.

Saiet Naderi et al [49](2005) stated that the PICD ranged from 35.1mm to 48.3mm with an average of 41.6mm.

Emine et al [10](2006) reported that the PICD varied from 33mm to 50mm with an average of 44.2±3.2mm.

Gagandeep Singh et al [15](2012) reported that the maximum intercondylar distance of male and female were 26.15mm and 24.71mm respectively.

Fathy Ahmed Fetouh et al [12](2013) recorded that the PICD ranged from 35.5mm to 48.5mm with an average of 41.4mm.

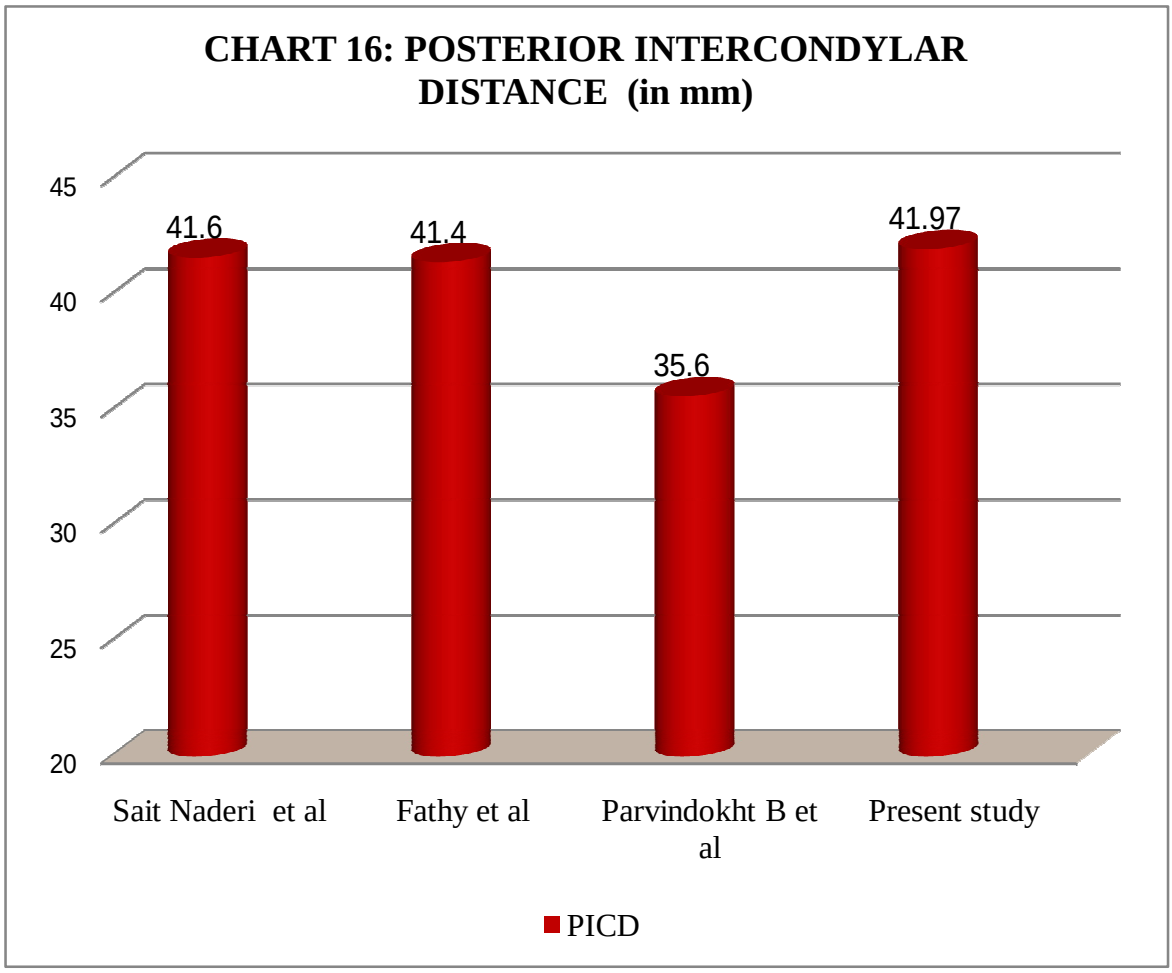
K. Natasis et al [31](2013) found that the mean anterior inter condylar distance was 51.61±5.01mm.

Parvindokht Bayat et al [39](2014) reported that the PICD varied from 13mm to 44mm with an average of 35.60±8.4mm.

In the **Present study** the PICD was in the range of 38.02 mm to 45.43 mm with an average of 41.97±1.67mm. The values of present study coincided with other studies.

TABLE 39: COMPARISON OF POSTERIOR INTERCONDYLAR DISTANCE

Sl. No	STUDY	YEAR OF STUDY	PICD (in mm)
1)	Sait Naderi et al	2005	41.60
2)	Fathy Ahmed Fetouh et al	2013	41.40
3)	Parvindokht Bayat et al	2014	35.60
4)	**Present study**	**2014**	**41.97**



As occipital condyles bound the FM laterally and converge ventrally, the OCs have different ventral and dorsal dimensions. Hence, AICD and PICD showed different values. Transcondylar approach required condylectomy for optimum visualization to resect any lesion in the ventral or ventrolateral aspect of FM.

14) PRESENCE OF POSTERIOR CONDYLAR CANAL

Emel AVCL et al [9](2011) reported that the posterior condylar canal was absent unilaterally in 27% of skulls and bilaterally in 17% of the skulls.

K. Natsis et al [31](2013) found that the PCC was present in 75.5% , out of this on right side in 11.9% and on left side in 16.1% and bilaterally in 47.6%.

Jatin Goda et al [24](2013) observed that PCC was present in 70.31% bilaterally and in 20.31% unilaterally.

Ketu Chauhan et al[29] (2013) found that PCC was present in 6% on left side and bilaterally in 3.6%.

Parvindokht Bayat et al [39](2014) found that the PCC was present in 4% on right side, 16% on left side and bilaterally in 40%.

In the **Present study,** it was observed that the PCC was found in 40 skulls and absent in 60 skulls on right side.

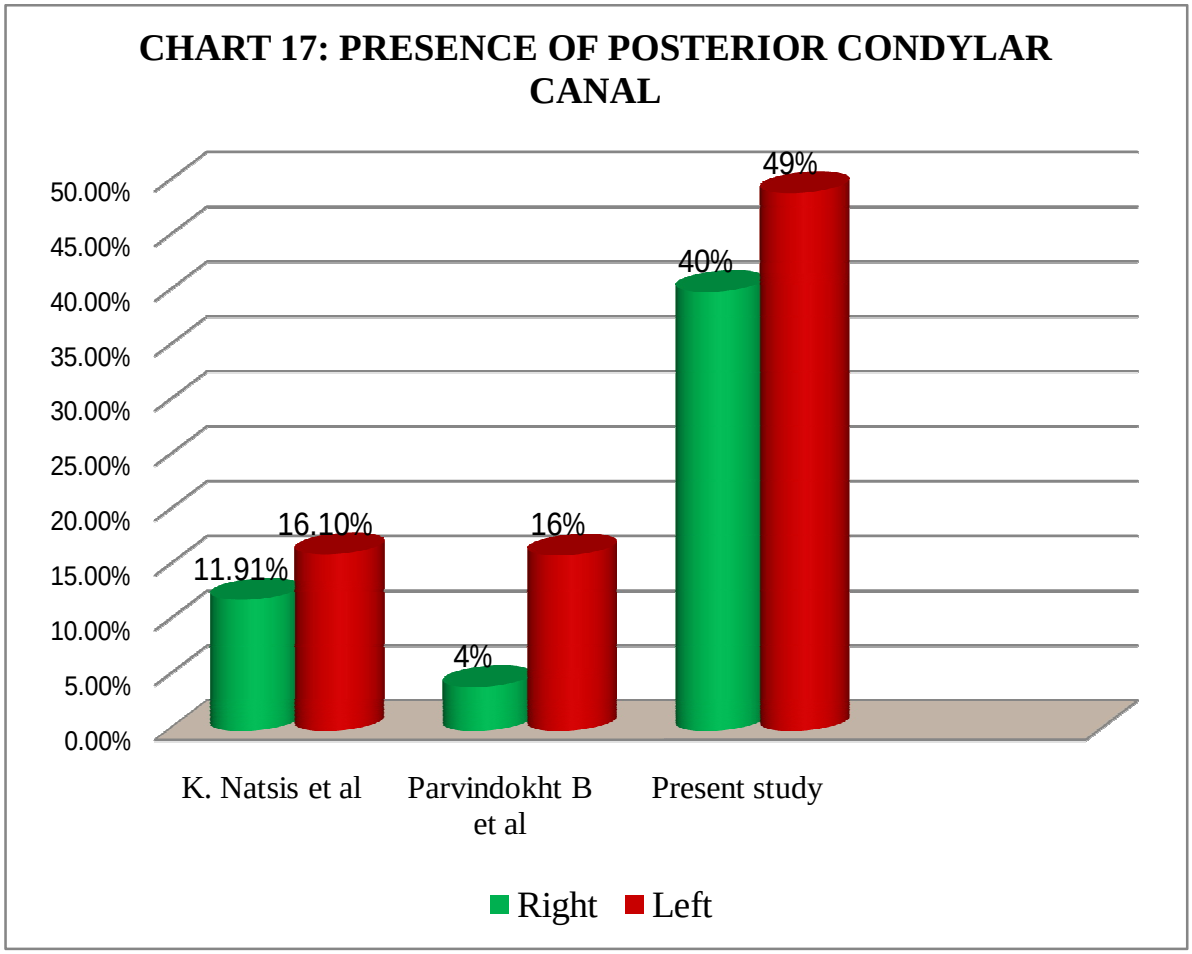
On the left side, it was found in 49 skulls and absent in 51 skulls. In around 33 skulls it was present bilaterally.

Through the PCC, an emissary vein and a nerve to the duramater of the posterior cranial fossa pass. On full extension of neck, compression of the structures passing through the PCC can occur, because the posterior margin of the atlas impinges itself into the condylar fossa.

The percentage of PCC in various studies was tabulated. This study showed greater values, which is significant.

TABLE 40: COMPARISON OF INCIDENCEOF POSTERIOR CONDYLAR CANAL (PCC)

SLNO	STUDY	YEAR OF STUDY	PRESENCE OF PCC		
			RIGHT	LEFT	BILATERAL
1)	K. Natsis et al	2013	11.9%	16.1%	47.6%
2)	Parvindokht Bayat et al	2014	4%	16%	40.0%
3)	**Present study**	**2014**	**40%**	**49%**	**33%**



15) PRESENCE OF SEPTUM OF THE HYPOGLOSSAL CANAL (HGC)

Muthukumar N et al [35](2005) reported that the HGC was divided into two compartments by a bony septum in 30% of the dry skulls

Nehi'r Barut et al [36](2009) found that 25% of HGC of dry skulls was divided into two parts by a bony septum.

Emel AVCL et al [9](2011) observed 30% of HGC of dry skulls was divided into two parts by a bony septum.

K. Natsis et al [31](2013) reported that the HGC septum was present in 25.5%.

Roopali et al [48](2013) stated that the septum of HGC was present in 3%.

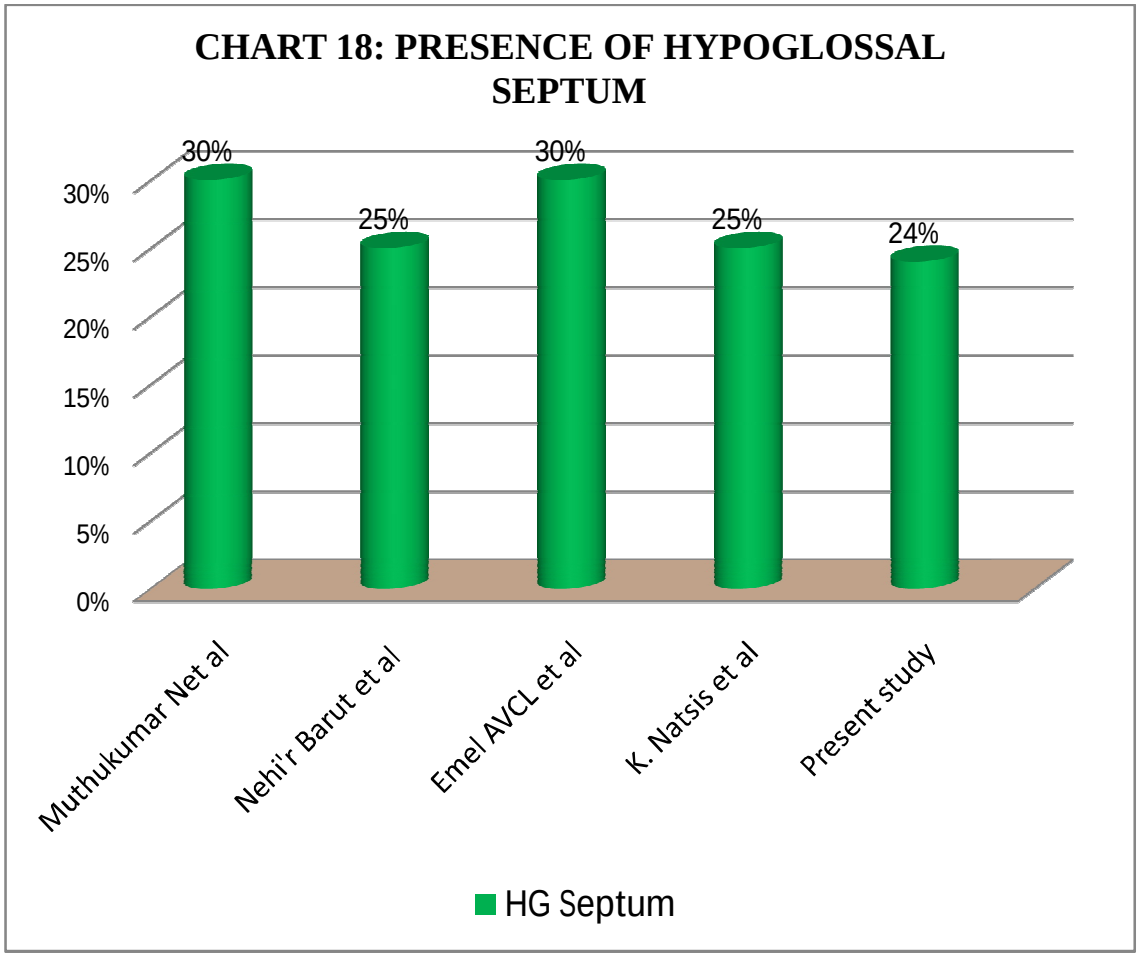
Singh Rajani [50](2013) found double condylar canal on right and single on left side.

In the **Present study** the HGC septum was present in 24%.

The HGC was divided by a spicule of bone partially or completely. This may be due to failure of union of the two bundles of HG nerve embryologically.

TABLE 41: COMPARISON OF INCIDENCE OF HGC SEPTUM

SLNO	STUDY	YEAR OF STUDY	PRESENCE OF HGC SEPTUM
1)	Muthukumar N et al	2005	30%
2)	Nehi'r Barut et al	2009	25%
3)	Emel AVCL et al	2011	30%
4)	K. Natsis et al	2013	25.5%
5)	**Present study**	**2014**	**24%**



16) DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HYPOGLOSSAL CANAL (RHGC) AND ANTERIOR MARGINOF ROC

Sait Naderi et al [49](2005) reported that the distance of the intracranial end of the RHGC from the anterior tip of the ROC was10.6mm.

Emine et al [10](2006) reported that the distance of the intracranial end of the RHGC from the anterior margin of the ROC varied from 8.1mm to 16.9mm with an average of 11.0±1.6mm.

Pereira G.A et al [42](2012) reported that the distance of the intracranial end of the RHGC from the anterior margin of the ROC was 11.0±1.8mm.

In the **Present study** the distance of the intracranial edge of the RHGC from the anterior margin of the ROC ranged from 7.51mm to 15.25mm with an average of 11.02±1.29mm.

TABLE 42: COMPARISON OF DISTANCE BETWEEN INTRACRANIAL EDGE OF RHGC AND ANTERIOR MARGIN OF ROC.

SLNO	STUDY	YEAR OF STUDY	DISTANCE BETWEEN INTRACRANIAL EDGEOF RHGCAND ANTERIOR MARGIN OF ROC (in mm)
1)	Sait Naderi et al	2005	10.60
2)	Emine et al	2006	11.00
3)	Pereira G.A et al	2012	11.00
4)	**Present study**	**2014**	**11.02**

17) DISTANCE BETWEEN INTRACRANIAL EDGE OF RIGHT HYPOGLOSSAL CANAL (RHGC) AND POSTERIOR MARGIN OF ROC

Muthukumar N et al [35](2005) found that the distance of the intracranial end of the RHGC from the posterior margin of the ROC was12.2mm.

Emine et al [10](2006) reported that the distance of the intracranial end of the RHGC from the posterior margin of the ROC varied from 8.2mm to 17.4mm with an average of 12.2±1.6mm.

Nehi'r Barut et al [36](2009) recorded that the distance between the intracranial edge of RHGC and posterior margin of ROC was 12.5mm.

Emel AVCL et al [9](2011) reported that the distance between the RHGC and Posterior border of ROC ranged from 7.9 mm to 12.2mm with an average of 9.8±1.1mm.

In the **Present study** the distance of the intracranial edge of the RHGC from the posterior margin of the ROC ranged from 9.8mm to 14.90mm with an average of 12.27±0.6mm.

TABLE 43: COMPARISON OF DISTANCE BETWEEN INTRACRANIAL EDGE OF RHGC AND POSTERIOR MARGIN OF ROC.

SLNO	STUDY	YEAR	DISTANCE BETWEEN INTRACRANIAL EDGE OF RHGC AND POSTERIOR MARGIN OF ROC (in mm)
1)	Muthukumar N et al	2005	12.20
2)	Emine et al	2006	12.20
3)	Nehi'r Barut et al	2009	12.50
4)	Emel AVCL et al	2011	09.80
5)	**Present study**	**2014**	**12.27**

18) DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HYPOGLOSSAL CANAL (LHGC) AND ANTERIOR MARGIN OF LOC

Sait Naderi et al [49](2005) reported that the distance of the intracranial end of the LHGC from the anterior tip of the LOC was 9.6mm.

Emine et al [10](2006) reported that the distance of the intracranial end of the LHGC from the anterior margin of the LOC was 11.3±1.5mm.

Pereira G.A et al [42](2012) recorded that the distance of the intracranial end of the LHGC from the anterior margin of the LOC was 10.7±1.8mm.

In the **Present study** the distance of the intracranial edge of the LHGC from the anterior margin of the LOC varied from 6.81mm to 15.18mm with an average of 10.93±1.3mm.

TABLE 44: COMPARISON OF DISTANCE BETWEEN INTRACRANIAL EDGE OF LHGC AND ANTERIOR MARGIN OF LOC.

SLNO	STUDY	YEAR OF STUDY	DISTANCE BETWEENINTRACRANIAL EDGE OFLHGC AND ANTERIOR MARGIN OF LOC (in mm)
1)	Sait Naderi et al	2005	9.60
2)	Emine et al l	2006	11.30
3)	Pereira G.A et al	2012	10.70
4)	**Present study**	**2014**	**10.93**

19) DISTANCE BETWEEN INTRACRANIAL EDGE OF LEFT HYPOGLOSSAL CANAL (LHGC) AND POSTERIOR MARGIN OF LOC.

Emel AVCL et al [9](2011) reported that the distance between LHGC and Posterior border of LOC ranged from 6.6 mm to 12.2 mm with an average of 9.9±1.4mm.

Emine et al [10](2006) reported that the intracranial end of the LHGC from the posterior margin of the LOC varied from 8.4mm to 17.6mm with an average of 12.4±2.3mm.

Nehi'r Barut et al [36](2009) found that the distance between the intracranial edge of LHGC and posterior margin of LOC was 12.6mm.

Pereira G.A et al [42](2012) reported that the distance of the intracranial end of the LHGC from the posterior margin of the LOC was 11.3±2.1mm.

In the **Present study** the distance of the intracranial edge of the LHGC from the posterior margin of the LOC ranged from 9.6mm to 14.5mm with an average of 12.26±0.59mm.

TABLE 45: COMPARISON OF DISTANCE BETWEEN INTRACRANIAL EDGE OF LHGC AND POSTERIOR MARGIN OF LOC.

SLNO	STUDY	YEAR OF STUDY	DISTANCE BETWEEN INTRACRANIAL EDGE OF LHGC AND POSTERIOR MARGIN OF LOC(in mm)
1)	Emine et al	2006	12.40
2)	Nehi'r Barut et al	2009	12.60
3)	Pereira et al	2011	11.30
4)	**Present study**	**2014**	**12.26**

The mean distance between intracranial edge of HGC (Right and Left) and anterior margin of ROC and LOC were measured as 11.02±1.29mm and 10.93±1.30mm respectively. The mean distance between intracranial edge of HGC (Right and Left) and posterior margin of ROC and LOC were measured as 12.27±0.6mm and12.26±0.59mm respectively.

The measured value was compared with various studies and tabulated. The values of present study coincided with other studies.

This is clinically significant for a safe occipital condyle resection. The OC can be safely drilled for a distance of 12mm from posterior margin before encountering the HGC and it is observed to be 12.27 ±0.59mm in our study.

HGC distance from anterior and posterior ROC and LOC of present study was compared with various studies and tabulated.

CHART 19: COMPARISON OF HGC DISTANCE FROM ANTERIOR MARGIN OF ROC AND LOC

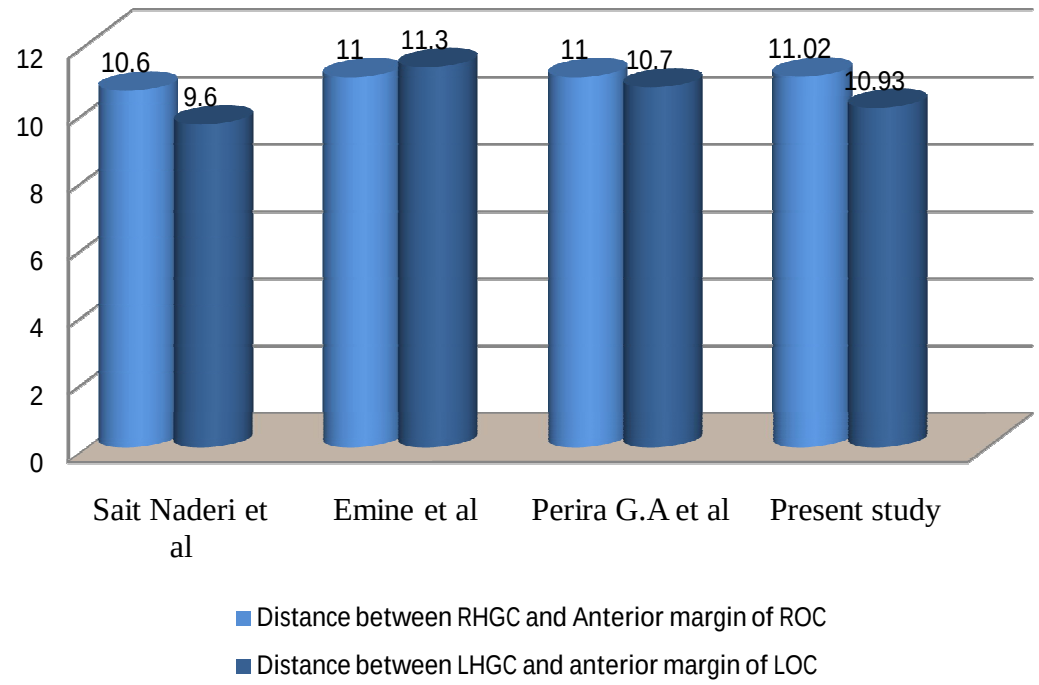
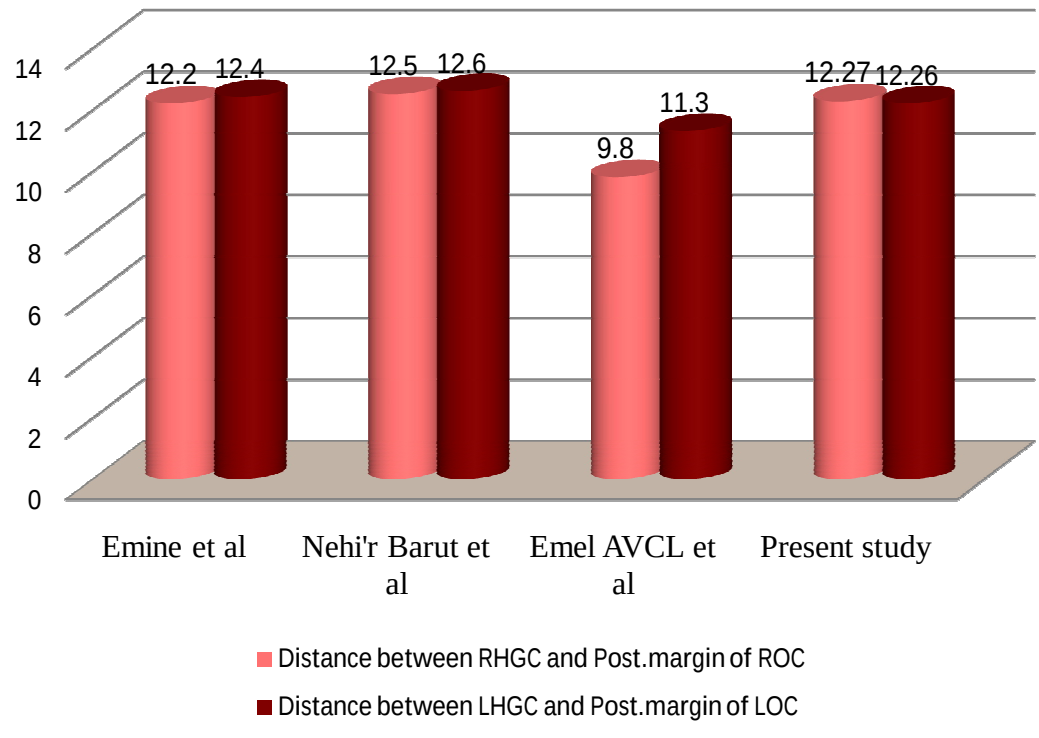


CHART 20: COMPARISON OF HGC DISTANCE FROM POSTERIOR MARGIN OF ROC AND LOC



Conclusion

CONCLUSION

An effort was made to assess the foramen magnum, occipital condyles and hypoglossal canals morphometrically through this study. Advances in skull base approaches have improved the surgical exposure in skull base surgeries. These manoeuvres may be complicated by injury to the neurovascular structures or craniocervical instability due to removal of occipital condyles. Hence, neurosurgeons performing this surgery should be familiar with the normal anatomy as well as variations of the foramen magnum region.

The parameters were measured and compared with other studies. The following were the conclusions derived from the present study:

- In the present study, it was found that the foramen magnum was oval in 40%. This variation in configuration should be taken into consideration during neuroimaging techniques and skull base surgery.

- The mean Anteroposterior diameter of the foramen magnum in adult dry skulls and cranial CT were measured as35.12±2.65mm and 35.03±0.95mm respectively. The size of the foramen magnum is the critical parameter in craniovertebral junction pathology for the manifestation of clinical signs and symptoms.

- The mean transverse diameter of the foramen magnum in adult dry skulls and cranial CT were measured as29.03±2.15mm and 28.79±1.17mm respectively. It is significant in transcondylar approach.
- Protrusion of occipital condyle was present in 20%
- The maximum length of the right and left occipital condyle were measured as 23.85±2.12mm and 23.77±2.29mm respectively.
- The maximum and minimum width of the right occipital condyle were measured as13.29 ±1.36mm and 6.86±1.34mm respectively.
- The maximum and minimum width of the left occipital condyle were measured as 13.44±1.41mm and 7.04±1.26mm respectively.
- The maximum length of right and left occipital condyle were measured as 23.11±0.73mm and 23.20±0.74mm respectively in cranial CT.
- The maximum width of right and left occipital condyle were measured as12.92±0.65mm to 12.88±0.69mm respectively in cranial CT. In the present study the measurements of dry skull were greater than those of cranial CT scans.

The radiological analysis of foramen magnum and occipital condyle is required prior to craniovertebral junction surgery to prevent complications like craniovertebral instability and haemorrhage.

- The bicondylar distance was 47.23±3.10mm. It is useful in forensic medicine for sex differentiation.

- The anterior intercondylar distance was 20.81±2.40mm.

- The posterior intercondylar distance was 41.97±1.67mm.

- The posterior condylar canal was present in 40 skulls and absent in 60 skulls on right side. On the left side it was present in 49 skulls and absent in 51 skulls. It was present bilaterally in 33 skulls. In the present study there was higher incidence of posterior condylar canal.

- The Hypoglossal canal septum was present in 24%.

- The mean distance between intracranial edge of right hypoglossal canal and anterior margin of right occipital condyle was measured as 11.02±1.29 mm and from left hypoglossal canal and anterior margin of left occipital condyle was measured as10.93±1.3mm.

- The mean distance between intracranial edge of right hypoglossal canal and posterior margin of right occipital condyle was measured as12.27±0.60mm and from left hypoglossal canal and posterior margin of left occipital condyle was measured as12.26±0.59mm.

This distance is clinically significant for a safe occipital condyle resection during transcondylar approach and it was observed to be 12.27±0.59mm in this study.

The present study showed that the difference between radiological and anatomical measurements were insignificant, which strengthen the importance of preoperative radiological evaluation for achieving better surgical success.

The present study also revealed the various shapes of FM and its morphometry. The data obtained may be useful to neurosurgeons in analyzing the anatomy of craniovertebral junction for preoperative planning and management of skull base surgery. The findings will also be enlightening for Radiologists, Orthopedicians, Anthropologists, Morphologists and Clinical Anatomists.

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MASTER CHART – DRY SKULL METHOD

SKULL NO.	ANTERO POSTERIOR DIAMETER (mm)	TRASVERSE DIAMETER (mm)	RIGHT OCCIPITAL CONDYLE (ROC)			LEFT OCCIPITAL CONDYLE (LOC)			BICONDYLAR DISTANCE (BCD)	ANTERIOR INTERCONDYLAR DISTANCE (AICD)	POSTERIOR INTERCONDYLAR DISTANCE (PICD)	DISTANCE BETWEEN RIGHT HYPOGLOSSAL CANAL AND OC		DISTANCE BETWEEN LEFT HYPOGLOSSAL CANAL AND OC		SHAPE OF FORAMEN MAGNUM	PROTRUSION OF OCCIPITAL CONDYLE	PRESENCE OF POSTRIOR CONDYLAR CANAL	PRESENCE OF HYPOGLOSSAL CANAL SEPTUM
			LENGTH mm	MAX WIDTH	MIN WIDTH	LENGTH mm	MAX WIDTH	MIN WIDTH				ANTERIOR MARGIN	POSTERIOR MARGIN	ANTERIOR MARGIN	POSTERIOR MARGIN				
1	24.64	24.01	18.16	14.07	7.57	17.25	14.08	7.33	48.44	17.48	40.85	9.3	11.43	9.62	11.45	Egg	A	A	A
2	28.65	24.49	19.72	14.02	6.7	18.95	14.89	7.93	44.1	22.11	39.64	9.6	12.5	8.1	12.6	oval	A	A	A
3	29.62	24.72	19.87	13.31	7.71	19.96	14.03	7.71	51.95	22.26	44.33	11.86	12.32	11.82	12.52	Egg	P RL	P RL	A
4	30.66	25.72	20.25	14.4	8.91	20.06	15.04	8.09	48.3	24.32	42.38	9.2	12.58	9.04	12.58	Round	A	A	P RL
5	31.26	26.01	20.73	14.33	7.29	20.09	14.79	7.5	47.62	20.24	42.72	9.02	11.34	8.92	11.84	Irregular	A	P RL	A
6	31.33	26.3	20.73	14.93	8.2	20.25	14.41	10.32	50.43	22.23	44.42	9.59	12.65	9.58	12.65	Egg	A	PRL	PRL
7	31.4	26.35	20.75	13.98	6.02	20.3	15.68	8.62	53.75	24.32	44.25	7.51	12.32	6.81	12.22	Irregular	A	A	PRL
8	31.56	26.4	21.16	13.66	5.24	20.65	14.4	6.34	47.34	18.24	42.56	10.83	12.54	10.51	12.54	oval	A	PR	PR
9	31.67	26.41	21.22	12.31	8.35	20.8	14.35	7.29	47.9	14.87	40.42	10.27	11.52	10.02	11.54	oval	A	A	A
10	31.7	26.42	21.39	13.97	5.68	20.8	12.95	7.4	44.29	19.22	40.67	12.5	11.92	11.8	11.92	oval	A	PRL	A
11	31.77	26.66	21.46	9.76	4.96	20.86	16.44	6.02	47.2	23.15	44.47	11.1	12.05	11.87	12.25	Egg	PRL	PRL	A
12	31.97	26.74	21.48	13.3	3.25	20.88	12.06	5.8	43.29	19.64	39.74	10.53	11.54	10.03	11.54	Round	A	PRL	PL
13	32.09	26.74	21.5	11.26	6.1	21.05	11.58	4.7	47.12	20.23	41.05	9.64	11.93	10.04	11.85	Irregular	A	PL	PL
14	32.18	26.74	21.53	11.58	4.72	21.44	11.24	6.2	43.54	20.36	42.42	9.54	12.54	9.54	12.24	Round	A	PRL	PR
15	32.19	26.77	21.55	12.09	8.39	21.47	10.38	4.94	43.88	20.14	41.23	10.02	11.65	10.75	11.65	Irregular	A	PL	PL
16	32.68	27.08	21.6	12.92	6.58	21.53	12.7	5.91	44.18	24.43	39.7	11.1	12.58	11.65	12.54	Egg	A	PR	A
17	32.75	27.09	21.73	12.74	6.63	21.69	14.95	7.94	47.72	18.34	44.24	10.18	12.85	10.01	12.85	oval	A	PRL	PL
18	32.92	27.1	21.84	12.09	5.82	21.78	12.66	6.63	42.81	17.24	42.65	10.87	12.54	10.8	12.74	oval	A	A	A
19	33.01	27.13	21.87	12.26	7.49	21.92	13.72	7.39	46.19	21.35	41.44	9.82	12.54	9.8	12.54	Round	PRL	A	A
20	33.04	27.17	21.88	15.64	6.78	22.03	13.7	9.53	40.74	20.04	40.73	8.79	12.21	8.79	12.28	Hexagonal	A	A	PL
21	33.12	27.18	21.9	11.92	7.31	22.13	12.94	8.39	42.58	23.04	38.03	9.17	11.82	9.32	11.82	Egg	A	A	A
22	33.27	27.3	21.99	14.82	6.5	22.16	13.3	5.5	47.12	19.7	40.92	9.4	9.8	10.3	9.6	Egg	A	PL	A
23	33.4	27.32	22.15	13.02	7.18	22.26	13.08	5.15	49.89	22.43	44.19	11.45	12.54	10.28	12.56	Hexagonal	PRL	PL	A
24	33.53	27.48	22.28	11.72	5.1	22.31	13.13	7.27	46.29	21.07	41.57	9.65	12.54	9.65	12.5	Egg	A	PR	A
25	33.66	27.59	22.28	13.58	6.3	22.35	12.01	8.76	48.24	19.26	40.77	9.88	12.65	9.87	12.65	Hexagonal	A	A	A
26	33.71	27.6	22.37	10.43	10.08	22.37	10.75	9.88	44.44	20.68	41.52	11.8	12.32	11.8	12.32	Egg	A	A	A
27	33.81	27.6	22.52	12.54	8.41	22.39	13.39	6.89	48.58	23.32	41.66	11.78	12.34	9.17	12.32	oval	A	PL	A
28	33.84	27.62	22.58	13.29	7.4	22.52	13.73	6.01	46.9	18.17	41.34	10.33	11.45	10.95	11.46	oval	PRL	A	A
29	33.9	27.67	22.72	13.12	7.26	22.55	13.94	6.55	46.61	18.32	41.42	10.97	11.54	10.88	11.54	Hexagonal	A	PRL	A
30	33.96	27.75	22.78	12.98	8.16	22.58	14.08	6.3	46.3	17.19	40.84	9.46	12.54	9.56	12.44	oval	PRL	PRL	PL
31	34.05	27.75	22.92	13.92	6.12	22.64	16.04	8.81	50.58	24.31	41.72	11.68	11.53	11.68	11.58	oval	A	A	A
32	34.13	27.76	23.11	12.95	5.57	22.75	13.02	7.18	51	22.42	41.56	11.44	12.34	11.18	12.34	oval	A	PRL	A

33	34.19	27.76	23.22	12.01	6.44	22.88	14.64	6.93	45.8	18.2	41.73	10.02	12.45	10.48	12.65	oval	A	A	A
34	34.28	27.8	23.31	16.04	6.79	23.01	15.01	6.28	45.84	17.41	44.84	11.14	11.34	11.15	11.32	oval	A	A	A
35	34.3	27.82	23.39	12.7	6.47	23.12	12.8	5.5	46.99	16.42	38.75	9.88	12.12	9.84	12.22	oval	A	PRL	PRL
36	34.32	28.02	23.4	13.7	9.13	23.13	15.31	7.95	48.91	20.37	40.59	11.4	12.42	11.39	12.42	oval	PRL	PL	PL
37	34.4	28.06	23.4	12	4.25	23.25	14.02	7.08	47.6	22.32	39.22	10.31	12.24	12.56	12.24	oval	A	A	A
38	34.5	28.21	23.45	12.04	9.3	23.34	16.01	6.48	53.04	22.24	44.54	11.41	12.23	7.81	12.23	Round	A	A	A
39	34.53	28.45	23.49	11.58	5.5	23.39	11.67	6.37	47.28	20.17	42.54	11.52	12.52	11.44	12.52	Egg	PRL	PR	PL
40	34.53	28.57	23.49	12.66	5.94	23.4	11.29	5.81	41.46	21.2	41.82	10.78	12.65	10.78	12.65	Round	A	PRL	A
41	34.63	28.61	23.49	13.13	7.09	23.4	12.87	9.2	50.25	24.11	43.1	11.1	12.65	11.6	12.68	Oval	A	A	PRL
42	34.68	28.63	23.54	14.01	7.13	23.42	14.24	6.24	32.71	20.42	43.4	10.41	12.54	10.4	12.44	Pentagonal	A	A	A
43	34.74	28.68	23.58	14.08	7.04	23.42	12.5	9	50.3	24.01	42.54	11.15	12.32	10.09	12.12	Irregular	PRL	PRL	A
44	34.75	28.69	23.59	14.24	7.98	23.43	13.3	6.82	46.77	19.31	43.24	12.72	12.54	11.5	12.44	oval	A	PRL	A
45	34.86	28.72	23.62	14.9	7.32	23.44	13.8	6.04	44.6	18.32	41.73	12.71	12.32	12.44	12.25	oval	A	PRL	PL
46	34.99	28.73	23.64	15.08	9.77	23.52	13.96	8.04	46.96	19.24	41.74	9.48	11.45	9.4	11.45	oval	A	A	A
47	35.01	28.74	23.64	11.37	8	23.54	12.28	7.21	46.13	17.38	42.63	9.26	12.54	10.08	12.52	Hexagonal	PRL	A	A
48	35.02	28.75	23.68	13.18	7.44	23.62	13.14	8.35	48.69	21.43	40.65	10.37	12.25	10.28	12.24	oval	A	PRL	A
49	35.07	28.78	23.72	13.3	6.62	23.66	15.05	7.44	53.42	20.46	44.14	10.81	12.54	10.8	12.54	Irregular	PRL	PL	A
50	35.09	28.79	23.74	15.51	9.27	23.78	11.81	6.78	49.26	20.38	42.2	11.72	11.46	10.86	11.45	Pentagonal	A	PL	A
51	35.1	28.8	23.77	13.08	6.1	23.91	13.54	9.49	48.73	20.07	43.04	10.19	13.14	10.17	13.24	Irregular	A	PRL	PL
52	35.12	28.82	23.79	12.66	5.3	23.91	13.98	6.28	50.58	20.43	42.35	12.81	11.54	10.71	11.54	Egg	A	PL	A
53	35.13	28.94	23.81	13.37	6.2	23.93	11.19	7.24	45.54	18.44	41.53	10.64	12.25	10.6	12.15	oval	A	PL	A
54	35.16	29.01	23.9	13.86	5.96	23.94	13.18	7.33	47.84	24.17	40.26	12.7	12.75	12.8	12.75	oval	A	PR	A
55	35.22	29.1	23.9	12.9	6.93	24.01	12.91	5.07	45.96	23.41	41.08	10.5	12.52	10.5	12.5	oval	A	PRL	A
56	35.28	29.17	23.92	12.01	8.66	24.04	13.79	5.68	45.73	23.19	41.04	10.5	12.34	10.54	12.34	Irregular	PRL	PL	A
57	35.38	29.32	23.93	13.57	9.49	24.04	14.48	7.13	47.74	20.24	44.33	12.75	11.54	12.7	11.84	oval	A	A	A
58	35.52	29.35	24.01	13.23	6.86	24.07	12.74	5.04	44.86	22.41	38.02	10.62	12.42	10.6	12.4	oval	A	PL	A
59	35.56	29.53	24.17	11.08	7.22	24.1	14.75	8.3	49.87	18.42	41.52	10.98	12.85	10.98	12.85	Irregular	PRL	PRL	A
60	35.69	29.54	24.2	14.7	8.31	24.17	12.96	7.16	49.31	20.38	38.72	10.28	13.08	10.57	13.24	Hexagonal	A	PRL	A
61	35.7	29.58	24.28	13.82	10.62	24.18	12.21	8.7	47.43	21.34	42.6	10.54	12.53	10.54	12.53	Egg	A	A	PL
62	35.88	29.6	24.3	14.42	7.83	24.25	11.7	5.64	44.79	15.07	40.82	10.97	12.42	11.86	12.44	Hexagonal	A	A	A
63	35.89	29.63	24.47	12.22	5.63	24.38	12.01	8.5	47.4	19.23	45.43	10.51	12.65	10.5	12.55	Egg	A	PR	A
64	35.99	29.63	24.47	12.03	5.15	24.43	13.14	7.29	46.9	24.35	42.72	12.4	12.54	11.86	12.54	oval	A	A	A
65	36.12	29.64	24.48	12.24	5.64	24.49	15.08	7.32	50.03	18.24	41.54	11.96	11.65	10.81	11.35	oval	PRL	A	A
66	36.12	29.7	24.57	12.7	6.7	24.5	12.82	6.8	41.86	20.32	41.65	12.02	11.43	11.99	11.43	Egg	A	PRL	A

67	36.17	29.74	24.65	12.76	5.65	24.6	12.22	5.21	47.03	21.23	44.05	9.37	12.62	11.24	12.53	oval	A	PRL	A
68	36.18	29.76	24.72	13.94	7.86	24.63	12.32	5.21	47.03	18.43	42.33	9.37	11.84	11.24	11.8	oval	A	A	A
69	36.2	29.82	24.82	11.78	4.65	24.67	10.87	7.02	42	20.12	40.85	10.62	12.42	10.6	12.42	Irregular	PRL	PRL	A
70	36.3	29.84	24.84	12.27	6.73	24.68	12.7	5.59	48.9	23.34	39.42	9.63	12.43	9.65	12.43	Pentagonal	A	A	A
71	36.34	30.03	24.85	12.91	6.31	24.68	12.52	7.98	47.27	22.21	41.02	11.57	12.62	11.58	11.56	Irregular	A	PRL	PL
72	36.4	30.04	24.93	14.94	5.92	24.69	9.85	7.69	44.24	23.42	40.24	11.08	12.68	11.01	12.64	Round	A	A	A
73	36.65	30.07	25.12	11.88	4.55	24.75	13.4	9.91	47.46	24.22	44.22	10.39	12.74	9.06	12.65	Irregular	PRL	A	A
74	36.72	30.12	25.17	16.07	8.58	24.79	13.19	5.81	45.29	23.09	40.87	9.8	12.1	10.9	12.3	Egg	A	PR	A
75	36.74	30.13	25.18	16.19	7.23	24.85	15.11	5.4	44.65	20.35	40.87	11.9	12.65	11.8	12.65	Round	A	PL	A
76	36.9	30.15	25.22	13.66	7.61	24.86	13.26	5.86	44.24	23.14	41.24	11.55	11.54	10.55	11.52	Egg	A	PL	PR
77	37.1	30.16	25.23	10.39	8.64	25.11	14.19	6.87	47.78	18.04	41.42	12.43	12.65	12.42	12.65	Egg	A	PRL	A
78	37.14	30.22	25.32	13.36	7.74	25.17	16.2	8.5	49.11	18.26	44.33	11.15	12.55	11.05	12.55	Round	A	A	A
79	37.29	30.42	25.32	15.05	6.36	25.26	13.67	5.33	46.27	19.37	39.02	12.19	11.9	11.2	11.65	Irregular	PRL	PRL	A
80	37.44	30.67	25.36	12.65	5.06	25.28	16.09	7.24	51.62	18.22	42.41	13.47	12.54	13.42	12.52	Round	A	PL	PL
81	37.6	30.68	25.38	15.51	5.5	25.31	12.44	7.01	48.63	21.24	41.24	10.91	12.54	10.9	12.74	oval	A	PRL	A
82	37.61	30.74	25.42	13.66	7.51	25.61	12.13	6.8	46.65	22.13	42.32	11.93	12.23	11.93	12.12	Egg	PRL	A	PL
83	37.69	30.78	25.6	14.29	6.87	25.61	14.25	6.56	50.97	24.37	41.4	12.74	11.54	13.01	11.54	Irregular	A	PRL	A
84	37.8	31.14	25.74	12.69	6.26	25.63	13.82	8.13	47.93	23.38	43.51	11.4	12.85	11.32	12.85	oval	A	A	A
85	37.88	31.19	25.75	12.32	5.78	25.75	12.44	6.27	45.78	22.09	40.63	12.12	11.54	12.14	11.54	Round	PRL	A	A
86	37.92	31.26	25.76	13.97	6.03	25.78	12.08	6.03	50.94	20.4	44.46	12.28	12.42	12.29	12.42	Irregular	A	A	PRL
87	38.06	31.63	25.89	14.71	7.29	25.79	11.99	4.92	43.42	23.05	44.04	11.98	12.42	11.92	12.44	Egg	A	PRL	A
88	38.52	31.74	26.05	13.61	6.75	25.89	15.01	6.08	49.73	22.32	45.25	9.61	12.56	9.61	12.46	oval	A	A	A
89	38.59	31.75	26.13	12.01	4.74	26.03	14.02	6.84	46.04	19.26	43.54	11.65	13.25	10.86	13.25	Egg	A	A	A
90	38.62	31.76	26.33	11.84	6.33	26.27	12.73	6.74	45.48	25.16	41.75	13.67	10.63	11.5	10.64	Round	A	PRL	A
91	38.71	31.89	26.4	13.53	6.08	26.55	12.22	6.48	43.9	18.41	40.43	11.6	11.53	12.3	11.54	oval	A	A	A
92	38.86	32.01	26.58	15.8	7.13	27.1	15.08	7.03	50.43	20.03	44.56	10.41	12.45	10.89	12.45	oval	A	A	A
93	39.04	32.27	26.73	11.02	8.47	27.63	11.42	8.47	51.74	23.42	41.44	14.64	11.94	13.48	11.94	oval	A	PRL	A
94	39.25	32.28	27.03	13.23	5.68	27.7	12.97	7.54	48.56	20.25	44.35	12.6	12.54	12.04	12.84	oval	A	A	A
95	39.46	32.51	27.04	14.92	6.53	27.81	14.1	9.34	50.22	18.41	42.52	12.62	12.56	11.22	12.56	Round	A	PL	A
96	39.51	32.64	27.34	15.23	6.83	27.82	14.26	6.54	48.82	24.32	40.63	12.42	12.54	13.12	12.54	oval	A	A	A
97	39.75	33.79	27.75	11.91	6.5	27.86	14.34	6.84	49.52	24.18	41.43	12.03	12.6	13.44	12.74	oval	PRL	A	A
98	39.79	33.97	27.81	14.14	6.31	28.16	16.37	8.86	48.6	22.42	44.32	15.25	12.54	15.18	12.5	Egg	A	PRL	A
99	39.8	34.45	28.19	15.94	8.06	29.58	12.88	5.77	50.94	15.21	41.47	11.24	12.54	13.34	12.5	oval	A	A	A
100	39.89	35.98	32.68	15	7.4	32.02	16.78	7.4	52.27	24.04	44.64	12.3	14.9	11.9	14.5	Egg	A	A	PR

MASTER CHART – RADIOLOGICAL STUDY

CRANIAL CT IMAGE NO.	ANTERO POSTERIOR DIAMETER (mm)	TRASVERSE DIAMETER (mm)	RIGHT OCCIPITAL CONDYLE		LEFT OCCIPITAL CONDYLE	
			LENGTH (mm)	WIDTH (mm)	LENGTH (mm)	WIDTH (mm)
1	35.47	27.65	23.24	11.34	23.32	11.43
2	36.4	27.44	22.81	12.34	22.45	12.45
3	33.54	27.45	22.48	12.84	22.55	12.32
4	34.64	28.94	22.62	13.24	22.53	13.23
5	34.85	28.29	24.33	12.84	24.54	12.45
6	34.79	30.28	23.25	13.86	23.34	13.76
7	36.66	27.43	22.46	11.56	22.45	11.65
8	34.53	29.67	22.87	12.86	22.73	12.76
9	33.13	28.53	24.32	13.26	24.34	13.65
10	34.04	28.43	23.32	13.86	23.45	13.98
11	36.22	28.61	23.62	13.03	23.64	13.05
12	36.54	30.34	22.26	12.65	22.23	12.86
13	34.56	29.43	23.43	13.42	23.56	13.85
14	35.46	30.45	22.44	12.67	22.58	12.74
15	35.65	27.65	24.23	13.45	24.45	13.04
16	34.75	30.25	23.42	12.86	23.45	12.56
17	34.45	28.85	22.12	12.76	23.25	12.54
18	35.42	30.83	22.32	13.67	22.38	13.58
19	35.04	27.29	22.56	13.43	22.75	13.42
20	34.48	28.04	24.24	12.56	24.18	12.45